ARMATURE CONSTRUCTION

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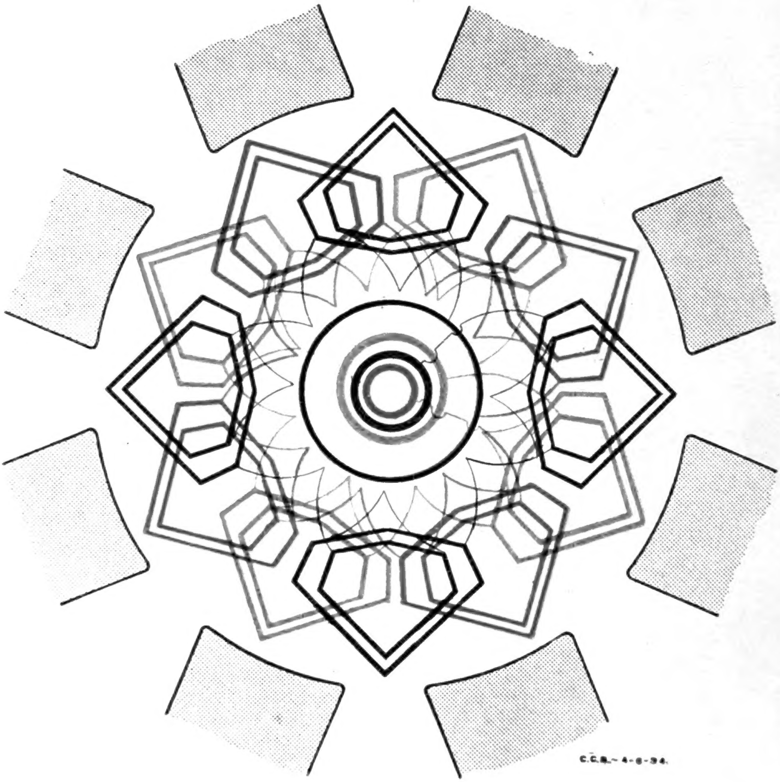
ARMATURE CONSTRUCTION



Three-phase Alternating-Current Armature Winding.

ARMATURE CONSTRUCTION

BY

H. M. HOBART, B.Sc.
M.Inst.C.E., M.I.E.E., Mem.A.I.E.E.

AND

A. G. ELLIS
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PREFACE

It is coming to be recognised that the design and manufacture of dynamo electric machinery is so extensive a subject that it cannot be sufficiently comprehensively handled in a single treatise.

In the present work the subject has been approached from the constructional and practical standpoint rather than from the designing and calculating standpoint. Thus, the theoretical and designing elements have not been allowed to predominate, but only enter so far as to facilitate an intelligent appreciation of the various methods and points encountered in the construction. For instance, in the chapters dealing with windings, the subject is dealt with in the aspect of the practical possibilities of the windings, the electromagnetic properties not being considered to such an extent as they would be in a more general or more theoretical treatise.

The authors wish to take this opportunity of making acknowledgment of a great amount of cordially rendered assistance from Mr H. W. Turner, with whom one of the present authors collaborated recently in a treatise entitled *The Insulation of Electric Machines.* While that work is devoted exclusively to insulation in the manufacture of electric machines, the present work deals in a similar way with armature construction, and is a further illustration of the large and detailed treatment required by dynamo electric machinery.

In providing illustrations of the various processes in the construction of armatures, the authors have been greatly assisted by the receipt of, and the permission to use for this purpose, numerous photographs and drawings from manufacturers and designers. We should regret inadvertent omission of the names of any amongst those who have in this manner so greatly assisted us, but we believe that the complete list consists of Messrs Alioth of Basel, The British Electric Plant Co. of Alloa, Messrs Adolf

Unger Aktiebolaget of Arbra, Mavor & Coulson of Glasgow, the Allmanna Svenska Aktiebolaget of Westeras, Messrs Vickers, Sons & Maxim of Sheffield, Bruce, Peebles & Co. of Edinburgh, Scott & Mountain, The Lancashire Dynamo and Motor Co. of Manchester, Messrs Dick, Kerr & Co., The Lahmeyer Electrical Co., The British Westinghouse Co., The British Thomson-Houston Co., and the firms whose names are given on p. 55; together with the engineers through whom we proffered our requests, comprising Mr Ernst Danielson, Mr H. A. Mavor, Prof. J. Epstein, Mr Aubrey V. Clayton, Dr Max Breslauer, Herrn Direktor Buchi, Dr William Hess, Mr W. C. Mountain, Mr R. D. M'Leod, Mr A. D. Williamson, Herrn Ingenieur Frucht, Mr J. S. Peck, Mr S. von Ammon.

We would also take this opportunity of expressing our appreciation of the care bestowed on the Index by Miss E. Walpole.

We are also indebted to the following journals for illustrations of practical processes:—*Electric Journal*, *Engineering*, *American Machinist*, *Zeitschrift des Vereines deutscher Ingenieure*.

We wish to draw special attention to the enterprise of our publishers in the employment of colours in the printing of the winding diagrams. Over twelve years ago, one of us went to a great deal of pains to prepare coloured winding diagrams for publication, only to be informed that the proposition was too fantastic, and that new diagrams with different styles of black lines should be substituted.

The use of coloured diagrams is of great advantage in studying polyphase windings and multiplex continuous current windings; and although to a mind which is continually dealing with such windings they are not so necessary, in the present case, where the aim has been to study the evolution of polyphase windings, and in a manner as explicit as possible, there is no doubt as to their utility. If at that date our present publishers' enterprise had been available, the credit for first printing winding diagrams in colours would not have passed, some eight years subsequently, to another author and publisher. The frontispiece is a reproduction of one of the diagrams thus prepared in 1894.

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ARMATURE CONSTRUCTION

CHAPTER I

INTRODUCTORY

A DYNAMO electric machine comprises a stator and a rotor, *i.e.* a stationary element and a rotating element. The armature is that part of the machine, whether stationary or rotatory, on which, in a suitably arranged system of electrical conductors, there are induced electromotive forces consequent upon the relative motion of the armature system and the magnetic field.

The armature is connected to the mains; in the case of generators it supplies current to the mains, and in the case of motors it receives current from them. In commercial dynamos and motors of the continuous-current type the armature is the rotor; in alternating current dynamos and motors it is generally the stator. A modern armature for either of these classes of dynamo electric machinery comprises a laminated iron core, upon which insulated circuits of copper, constituting the armature winding, are suitably located. In the case of continuous-current machinery, as well as in some types of alternating-current machinery, the armature winding is suitably connected to the segments of a commutator Armature core, armature winding and commutator, together with the spider or spiders, and shaft, constitute the armature of a continuous-current dynamo-electric machine; the magnet frame and the field windings constituting the so-called "field." In the case of the stationary armatures of alternating-current dynamo-electric machines, the armature core and windings are still the principal components. The commutator is absent, the ends of the windings being carried to suitable terminals. Instead of the spider and the shaft, other suitable structural parts are provided. As the armature core and the armature windings are common to both rotating and stationary armatures, their construction will be taken up in the earlier sections of this treatise, the discussion of commutators being deferred to a subsequent chapter, since they are required only in rotating armatures.

The extensive introduction in recent years of the terms "rotor" and "stator" is liable to lead to misunderstandings. The terms are not synonymous with the terms "armature" and "field." Thus Fig. 1 illustrates the rotor of a dynamo-electric machine; the part "A" is, however, an armature, and the part "B" is a field. Structures such as "A" come within the scope of this

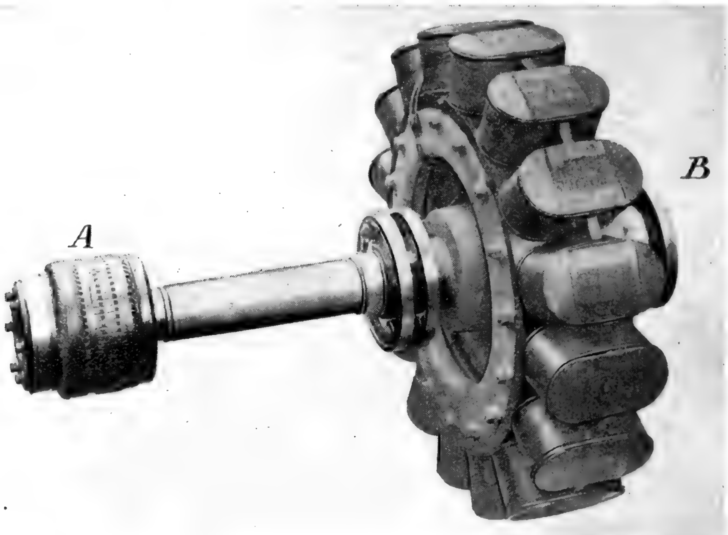


FIG. 1.—Rotor of Alternating Current Generator with Exciter Armature. Dick, Kerr & Co.

treatise; structures such as "B" do not. "A" is an internal rotating armature; "B" is an internal rotating field.

Fig. 2 is another example of an internal rotating armature. "C," the commutator, "D," the armature core, and "E," the armature winding, will in this treatise all be considered as components of the armature, as will also the armature spider, an instance of which may best be seen at "S" in the unwound armature of Fig. 3. In the example shown in Fig. 3, the armature spider comprises a hub H, arms A, and end flanges F F. In this case the commutator spider, B, constitutes an integral part of the armature spider, but a separate spider is often employed for the commutator. The commutator clamping rings are seen at R R:

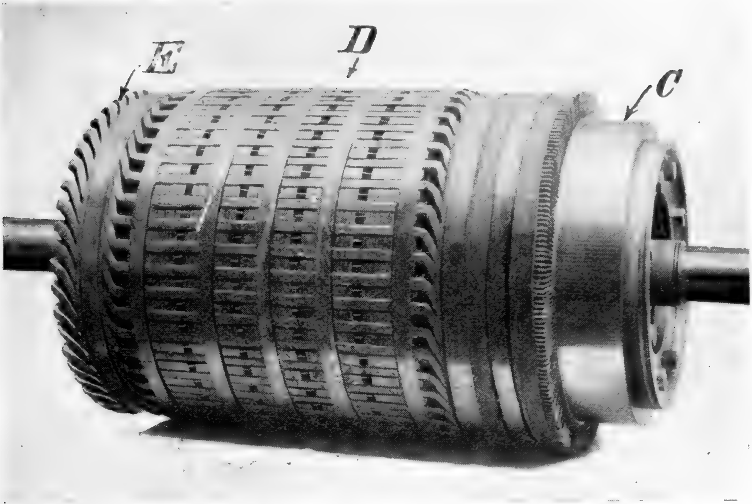


Fig. 2.—Armature of 50 H.P., 300/750 r.p.m., 440 Volt Variable Speed Motor Vickers, Sons & Maxim.

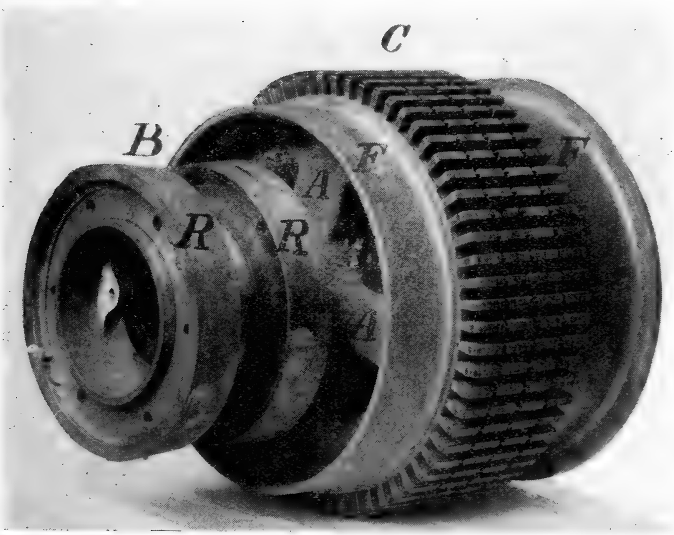


Fig. 3.—Unwound Armature of Continuous Current Machine. British Electric Plant Co.

in this case the inner ring is an integral part of the armature and commutator spider. The armature core, C, is formed of "core plates" or "armature laminations" of sheet steel. Sometimes the armature is built up on the shaft, but often, as in Fig. 3, the shaft is pressed into the hub of the completed armature.

FIG. 4.—Stationary Armature of Alternating Current Motor. Scott & Mountain.

For the sake of uniformity, the shaft will not be considered as part of the armature.

In Fig. 4 is given an instance of the frame and core of an external stationary armature or "stator." But stators are not necessarily armatures. In the case of continuous-current dynamo-electric machines, the stator is generally the field, and, as such, is not dealt with in this treatise. But when the stator is an armature, as in Fig. 4, it is considered as coming within the scope of this treatise. The armature shown in Fig. 4 is

FIG. 5.—Wound Stator of Alternating Current Machine. Lancashire Dynamo and Motor Co.

not wound. A is the core, B is the frame, C is an end shield for protecting the windings, and D is one of the end flanges of the frame. Fig. 5 represents a wound stator, *i.e.* an external armature with its winding in place, but with the end shields removed. Such an armature may be suitable either for an alternating-current generator or synchronous motor, or for an induction motor. In the case of an alternating-current generator or synchronous motor, the internal rotor is a "field," and does not come within the scope of this treatise. Strictly speaking, this is equally true of the rotor of an induction motor, when the primary winding is on the stator and the secondary is on the rotor; nevertheless, since the construction of such an induction motor "field" is utterly unlike the ordinary conception of the "field" of a dynamo-electric machine, and is, in fact, practically identical in most respects with the construction of a rotating armature, it has been decided to include in this treatise the rotors of induction motors. These—as, of course, also all the above

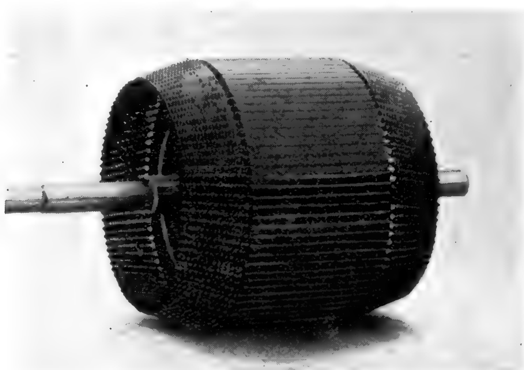


FIG. 6.—Induction Motor Squirrel-cage Rotor. Almanna Svenska Elektriska Aktiebolaget.

types—will be taken up in detail in the course of this treatise. At this point it will suffice to refer to Figs. 6 and 7, in which two typical examples of induction motor "rotors" (still often termed "armatures") are given.

Fig. 6 has a short-circuited rotor winding commonly called a "squirrel-cage" winding, which denomination is suggested by its appearance.

Fig. 7 represents a wound rotor for an induction motor in this case, although this rotor would do equally well for the armature of an alternating-current generator.

The rotor of an induction motor may be regarded as an armature by virtue of its having E.M.F.'s induced in it; and hence it has been included, as well as the stator, in this treatise.

For the purpose of making clearer the distinction between the parts stator, rotor, armature, and field of dynamo-electric machines, a chart is given in Fig. 8 which shows an outline sketch of the five common classes of dynamo machinery, with the parts which comprise the stator and rotor tabulated in columns.

In the outline sketches the armature is marked A and the field system F. Also in the columns designated stator and rotor, the armature system, wherever it occurs, is entered in heavy type. It is with the parts marked A, and entered in heavy type, that the present work deals.

In all of the cases shown in Fig. 8 the stator is external to the rotor, and the rotor revolves inside the stator.

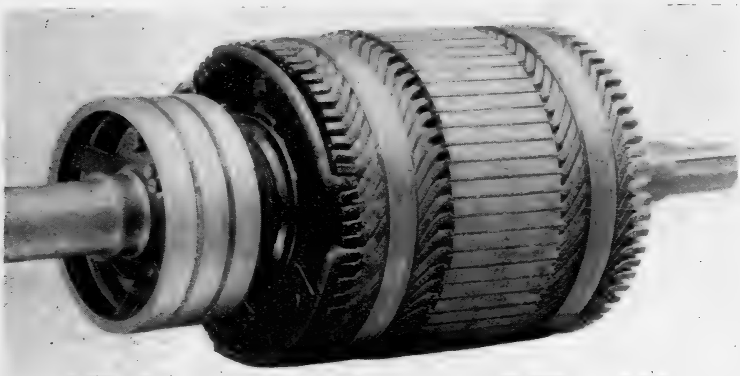


Fig. 7.—Wound Slip-ring Rotor. Alioth Co.

There have been a few machines built which depart from this practice, but these are so very rare and old that they are not included here.

Under Class I. — Continuous - Current Generators — some machines were once built by Messrs Siemens & Halske, having a revolving armature with stationary poles at the interior of the armature. The armature was gramme ring wound, the conductors on the outside of the periphery forming the commutator on which the brushes pressed.

Were this type of machine used now to any extent, we should have inserted it in the chart of Fig. 8 as a type B continuous current machine of the inner pole type; the armature, however, would still be the rotor.

In Class III.—Alternators—some machines have been built by the Westinghouse Co., having a stationary armature with

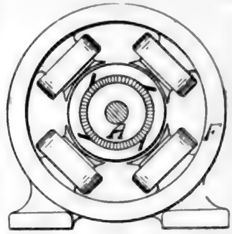
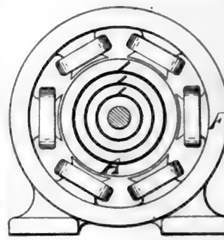
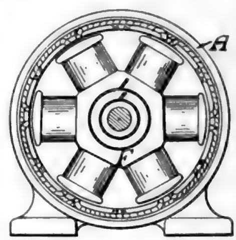
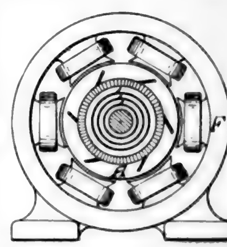
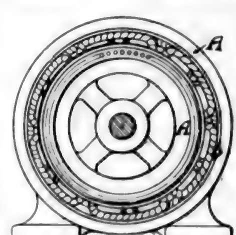
Designation of Machine.	Stator.	Rotor.	Outline Sketch.
I. Continuous Current Generator and Motor.	Field System.	**Armature and Commutator.**	
II. Alternating Current Generator, Type A.	Field System.	**Armature and Slip-rings.**	
III. Alternating Current Generator, Type B, and Synchronous Motor.	**Armature.**	Field System.	
IV. Rotary Converter.	Field System.	**Armature Commutator and Slip-rings.**	
V. Induction Motor.	**Stationary Wound Armature (receiving current from line).**	**Rotating Armature either (*a*) Wound, with Slip-rings; (*b*) Short-circuited Squirrel-cage.**	

FIG. 8.—Chart showing classification of parts of Dynamo Electric Machines.

a revolving field external to it—not internal to it, as in the type shown. In this case the poles projected radially inwards from a large rotating frame.

There is also another class of machine which has not been inserted—the Alternating-current Commutator Motor.

As this is still in the developmental stage, its many types could not be so classified as to be easily brought within the scope of Fig. 8. So far as relate to construction, the treatment of stationary and rotating armatures and commutators in this work will apply generally to the Alternating-current Commutator Motor.

CHAPTER II

ARMATURE LAMINATIONS

It was formerly the opinion that the softest Swedish charcoal iron was the most suitable material for armature laminations. But some fourteen years ago attention was drawn to the phenomenon of "ageing,"[1] in virtue of which the hysteresis loss increases when iron is subjected for long intervals to temperatures of 60° Cent. and higher. The increase in hysteresis loss by "ageing" is generally slow, but it is nevertheless liable to be ultimately sufficient to be detrimental to the performance of the apparatus. Although the disadvantage is most marked in the case of stationary transformers, it has also been found desirable to alter the composition of the material employed in armature cores, partly in consequence of the investigations of this phenomenon of "ageing," and partly in consequence of the improvements which have been made in the production of sheet steel. For the rate of deterioration through "ageing" may in general be said to be most marked in soft Swedish charcoal iron, and to be quite low or even altogether absent in certain qualities of sheet steel. It is often the very cheapest qualities of sheet steel which are the most suitable as regards freedom from "ageing." The permeability of such sheet steels is, on the whole, inferior to that of sheets rolled from charcoal iron, and the initial hysteresis loss may be somewhat higher. But both of these disadvantages may be greatly reduced by annealing the sheets from a suitably high temperature, *i.e.* from the highest temperature which it is practicable to employ without causing in the adjacent plates any

[1] "Ageing" is defined by the German rules for iron as the percentage variation of the figure of loss caused by keeping the sample at a temperature of 100° over 600 hours. The "figure of loss" is defined as the loss in watts per kg. measured with a density of 10,000 lines per sq. cm. and a frequency of 50 cycles per second. (*See* "Selection and Testing of Materials for Construction of Electric Machinery," Prof. J. Epstein's paper read before Inst. Elec. Engrs., Nov. 22, 1906.)

tendency to stick together in the piles in which they are arranged in the annealing ovens. It is practicable to anneal some qualities of plates from a temperature of 900° Cent.

It is very difficult to find a material of good initial quality that will not "age" as the result of prolonged exposure to temperatures much above 60° Cent. A sheet of the composition set forth in the following table has been found to be very satisfactory. Its initial hysteresis loss is fairly low when it is suitably annealed, and in a number of samples tested there has been found to be practically no "ageing" as the result of prolonged exposure to a temperature of 60° Cent.

Composition of a low "ageing" sheet steel.

Carbon	0·06 per cent.
Silicon	0·01 ,,
Phosphorus	0·08 ,,
Manganese	0·5 ,,
Sulphur	0·03 ,,

Equally satisfactory results have, however, been obtained with materials of very different compositions.

A specification on the following lines has been employed with good results:—

"The sheets are to be of the best quality of sheet steel, and rolled to a smooth, plane surface. Each sheet is to be freed from scale by pickling, or otherwise, and cleaning, to be followed by cold rolling.

"Sheets delivered under the contract must be uniform in quality, composition, and treatment, should show no detachable scale, and should not be annealed after the last rolling. The maximum of impurities allowable is as follows:—

"Carbon	0·08
Silicon	trace, or less than 0·009
Phosphorus	0·06
Manganese	0·40
Sulphur	0·05

"Any sheet showing less of impurities than the foregoing will, if otherwise in accordance with specifications, prove acceptable; but the composition, when determined upon, must be kept to a uniform standard."

The writers, however, prefer the composition given in the previous table.

Armature cores are almost always built from laminations of 0·5 mm. thickness. The use of a single standard thickness is justified from the standpoint of requiring a minimum supply to be kept in the stores; but from the strictly technical standpoint, sheets of very different thickness should be employed in designs for various purposes. The choice should be dependent upon the periodicity and speed of the machine, and also upon the induced volts per cm. length of armature core in a direction parallel to the shaft. There are many cases where sheets much thicker than 0·5 mm. could be employed with advantage—such for instance, as for the cores of the rotors of induction motors.

On the other hand, not much, if anything, can be gained by the use of sheets of less than 0·5 mm. thickness; for this entails a high percentage of total thickness of insulating varnish. As the thickness of insulating varnish per sheet cannot be reduced much below 0·03 mm., it is obvious that the total percentage lost space will be greater the greater the subdivision of the core. Thus, taking 0·03 mm. as a representative thickness of Japan varnish, and 0·02 mm. as the lost space through lack of uniformity of the sheets as pressed up between the armature core flanges, then the total core length per lamination (exclusive of ventilating ducts) may, for various thicknesses of laminations, be derived as set forth in Table I.

TABLE I.

SPACE OCCUPIED BY CORE PLATE INSULATION.

Thickness of bare core plate in mm.	0·20	0·30	0·40	0·50	0·60
Thickness of insulating varnish or other coating per core plate .	0·03	0·03	0·03	0·03	0·03
Thickness of residual lost space per core plate	0·02	0·02	0·02	0·02	0·02
Total thickness allowance per sheet	0·25	0·35	0·45	0·55	0·65
Percentage of iron	80%	86%	89%	91%	92%

The thinner the plate, moreover, the greater will be the percentage which the skin of inferior magnetic quality bears to the total thickness of the plate. The price also increases with decreasing thickness. To sum up, it may be said that experience has shown 0·5 mm. (20 mils.) to be a satisfactory value for most purposes, and in the interests of standardisation it is preferable to employ this value in almost all armature cores. Departures from this value will the more often be justified in order to employ thicker sheets, than in order to employ thinner sheets.[1]

There is such a great variation in the quality of sheet iron, even when obtained from the same manufacturer, that it is hopeless to obtain any approach to uniformly satisfactory results unless the material is ordered to comply with a suitable specification,

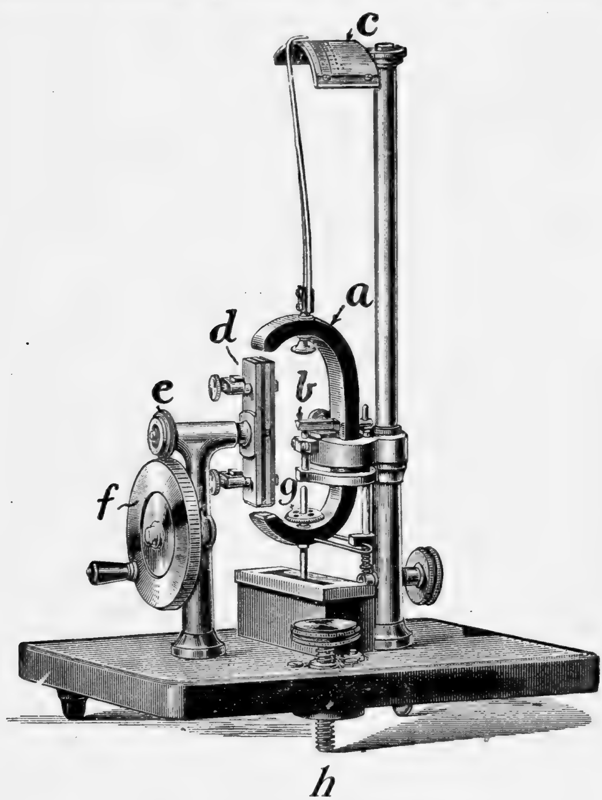


Fig. 9.—Ewing Hysteresis Tester.

and ultimately ruthlessly rejected if unsatisfactory. Otherwise, cases will frequently arise of machines overheating when on test, due to excessive core loss. The Ewing hysteresis tester is widely employed in England, and is a very convenient instrument with which to control the hysteretic quality of the samples received.

Fig. 9 is a photograph of this hysteresis tester. The instru-

[1] According to Brunswick and Aliamet (*Construction des Induits à Courant Continu*, Partie Mécanique, p. 57), the thickness of sheet iron most generally employed in France for armature discs is 0·4 mm.

ment has a magnet *a*, pivoted on a knife-edge supported by an agate bearing. The magnet carries a pointer which reads over the scale *c*. The sample strips, 3 inches (76 mm.) long and $\frac{5}{8}$ inch (15·9 mm.) wide, which are cut from the laminations of sheet iron, are secured by clamps to the carrier *d*, and are rotated between the poles of the magnet *a* by means of the friction wheel *e* and the driving wheel *f*, thus producing reversals in the magnetisation of the sample strips. Owing to the hysteresis loss in the iron, a couple is exerted on the magnet *a*, thereby causing a deflection of the pointer. Owing to windage and to hysteresis in the permanent magnet, a certain deflection would be obtained even if the sample had no hysteresis loss. With the scale generally supplied with the instrument, this deflection is about 30. If, however, 30 is subtracted from the reading obtained with a given sample, the residual deflection will be approximately proportional to the hysteresis loss in the sample. It is thus convenient to add to the scale as provided, a series of figures—say, in red ink—with 0 corresponding to 30 of the original scale, assigning to the other portions of the scale values less by 30 than the values of the original scale. There are thus two "zeros" to the right and left of the centre of the scale, and an ungraduated portion between them. Let us designate this as the scale of "residual deflections." This proposition will be better understood by considering an actual case, where measurements of three samples of previously ascertained hysteresis loss gave the results set forth in Table II.

Table II.

DETERMINATION OF CONSTANT FOR EWING HYSTERESIS TESTER.

Designation of sample.	Hysteresis loss in watts per kg. at a density of 4000 lines per sq. cm. and a periodicity of 50 cycles per second.	Deflection on original scale.	"Residual deflection" (= Deflection on original scale − 30).	Constant by which to multiply the "residual deflection" in order to obtain the hysteresis loss in watts per kg. at 4000 lines and 50 cycles.
I.	1·60	162	132	0·0121
II.	1·17	125	95	0·0120
III.	0·44	66	36	0·0122
		Mean Constant		= 0·0121

Hence to determine the absolute value of the loss, the "residual deflection" produced by the test sample is compared with the "residual deflections" produced by the samples having known and stated amounts of hysteresis. In practice, therefore, the method is absolutely empirical, and is free from all theoretical assumptions. In Fig. 10 is shown a scale calibrated in the manner described.

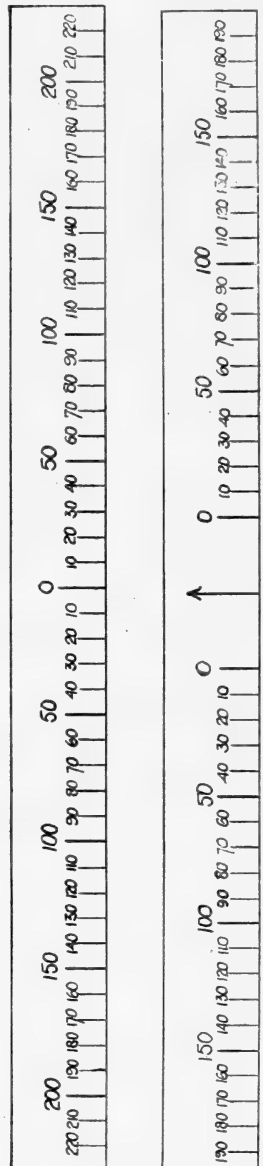


Fig. 10.—Scales for Ewing Hysteresis Tester.

The deflection of the pointer to one side should be read, and, again, the deflection to the other side when the direction of rotation is reversed. The average of these two readings gives a value proportional to the hysteresis loss. The deflection of the instrument is fairly independent of the speed at which the carrier revolves. If the rate is very slow, the magnet will show each individual impulse which it receives as the ends of the sample pass its poles; but when the speed is sufficiently increased, these impulses blend together into a steady deflection. A needlessly high speed should, of course, be avoided, as the windage set up would interfere with obtaining a correct reading.

For the test sample, as many strips are to be taken as will make up a weight approximately equal to the weight of one of the standard samples. No error is introduced by reasonable variation in this respect, and hence no exact adjustment of the weight is necessary. The length of the strips must, however, be exactly 3 inches. The number of strips required for the test sample will, in general, be six or seven pieces, *i.e.* for the usual gauges of transformer iron. The most customary thickness of each sheet is, as already stated, 0·5 mm. The magnetic induction is practically the same in all the specimens, notwithstanding the differences in the permeability of the iron; this is on account of the comparatively large air-gap between the specimen and the magnet poles. In the instrument as shown, the magnetic density in the samples will be about 4000 C.G.S. lines.

The damping of the swing of the magnet is produced by a dash-pot consisting of a little vane, which moves in a tank of oil. The degree of sensitiveness of the instrument is adjusted by raising or lowering the nut, *g*, on the lower side of the magnet; the centre of gravity of the oscillating system is thereby raised or lowered. The pointer is set to zero at the middle of the scale by means of the levelling screw, *h*, and also by means of a nut, which runs on a screw projecting laterally from the middle of the magnet. Since the average of the readings on both sides is taken, it is unnecessary to have the zero in exact adjustment; but it should be set near enough to prevent the scale readings on the two sides from being very different.

The instrument is also supplied with an arrangement for lifting the movable system from its bearing when not in use.

The tests should be made from pieces cut at random from different parts of the sheets whose quality it is desired to determine.

Large sheets may be tested *in bulk* for hysteresis and permeability by means of an apparatus which the Siemens-Schuckert Werke, of Vienna, have placed upon the market. The sheets to be tested are slid, by suitable means, into a large cylindrical drum so that they constitute a ring of about a meter diameter, with a section measuring a meter or more in one direction by a couple of millimeters or so in the other direction. This apparatus may be seen at the right in Fig. 15.

The frame is provided with a permanent annular winding enclosing the sheets, and from four to six sheets are thus generally tested together. The method permits of readily unloading and testing a few sheets from a given shipment, in order to determine whether or no the entire shipment shall be accepted.[1]

[1] For description of this apparatus, see an article by Richter, entitled "Eisenprüfapparat für ganze Blechtafeln" (*Elektrotechn. Zeitschr.*, 24, pp. 341–343, 7th May 1903).

The Ewing apparatus and the Siemens-Schuckert apparatus, as well as a number of other methods of testing sheet iron, are described in considerable detail in the first chapter of *Electric Machine Design* (a revised and enlarged edition of *Electric Generators*), London, *Engineering*, 1906.

On p. 187 of the *Elektrotechn. Zeitschr.*, for 5th March 1903, Brion describes a development from Richter's method. Brion's method permits of testing the sheets in the flat state, two sets of sheets being employed, and the ends joined by strips of such small length and large cross section that the loss in them may be ignored, or an approximate correction may be employed for the loss in the small strips.

While each manufacturer will find it expedient to draw up specifications adapted to comply with his own special requirements, it may be useful to those to whom the subject presents an aspect of novelty, to set forth a specification which, while ensuring fairly good material when complied with, cannot be said to impose any unreasonable condition upon the contractor for the material, and hence the material should be supplied at current market prices. The specification is as follows:—

"Samples shall be cut from various parts of several sheets selected at random from the shipment. When tested on a Ewing hysteresis tester by comparison with the standardised samples supplied with the instrument, the hysteresis loss at a density of 4000 C.G.S. lines per sq. cm., and at a periodicity of 50 complete cycles per second, shall not exceed 0·5 watts per kg."

If the Ewing hysteresis tester is not originally provided with standardised samples, then there should be obtained a number of samples (at least three) of widely different quality, whose hysteresis loss is known; and prior to and after the measurements on the samples to be tested, readings should be taken on all these standardised samples, and the constant of the instrument thus obtained for each particular occasion. Should the ratios of the readings obtained on the various standardised samples vary materially from the ratios obtained on prior occasions, it is an indication that, due to some cause, one or other of the samples has altered. The greater the number of standardised samples employed, the greater will be the certainty with which the defective sample can be identified and eliminated. Suppose that we have four standardised samples, I., II., III., and IV., whose hysteresis loss is known and stated, then we need first to standardise the Ewing tester—that is, to determine its "constant," or the factor by which the instrument readings ("residual deflections") must be multiplied to obtain the hysteresis in watts per kg.

Table III. is drawn up to allow of the entry of the necessary readings to determine this "constant." In column 2 should be entered the hysteresis loss corresponding to each of the samples I., II., III., and IV. Each sample should now in turn be put into the instrument, and four readings taken on each. These readings should be entered up in column 3. The average reading ("residual deflection") for each sample should then be calculated, and entered in column 4. Dividing this average deflection into the known hysteresis loss of the standard sample in column 2, we obtain the watts per kg. per degree "residual deflection" of the instrument.

This should be done for each of the samples I., II., III., and IV., and by taking the average of the four values of the instrument constant thus obtained, the mean constant for the instrument may be derived, and entered at the bottom of Table III.

TABLE III.

TABLE FOR RECORDING RESULTS OF DETERMINATION OF CONSTANT OF EWING TESTER.

No. of Standard Sample.	Specified Hysteresis Loss of the Sample in watts per kg., at a Density of 4000 Lines per sq. cm. and a Frequency of 50 Cycles per second.	"Residual Deflection" of the Instrument in degrees.	Mean "Residual Deflection" in degrees.	Hysteresis Loss in watts per kg. per degree of "Residual Deflection," at Reference Density (4000) and Frequency (50).
I.				
II.				
III.				
IV.				
Mean Constant of Instrument— Watts per kg. per degree of "Residual Deflection"—				

Having thus calibrated the instrument, we are in a position to determine the actual hysteresis loss in watts per kg. for any other sample of iron whose quality we desire to determine. After conducting a series of tests on any of the samples, the instrument should be again standardised and its constant re-determined, using another table such as Table III. The mean between the constants determined before and after the tests should be taken, and this value employed in calculating the results of tests on the samples tested. The results of tests on various samples should be recorded in tables, for which Table IV. is a convenient model:—

TABLE IV.

TABLE FOR RECORDING TESTS ON IRON.

Designation of Sample.	Description of Sample.	Date of Test.	Instrument "Constant" as determined on this date (*i.e.* Hysteresis Loss in watts per kg. per degree of "Residual Deflection," and corresponding to Density of 4000 Lines per sq. cm. and 50 Cycles per second). —A—	Degrees. Mean "Residual Deflection," with Sample under Test. —B—	Hysteresis Loss of Sample in watts per kg., at Density of 4000 and 50 Cycles per second (= A × B).

If we represent by 1·00 the hysteresis loss in watts per kg., when the density is 4000 lines per sq. cm. and the periodicity is 50 cycles per second; then for any other density, but the same periodicity, the hysteresis loss will be found by multiplying by the corresponding constant in Table V. Thus if, from the Ewing hysteresis tester results, we have ascertained that a certain sample has a hysteresis loss of 0·73 watts per kg. at 50 cycles per second, and a density of 4000 lines per sq. cm., we can determine the loss at a density of, say, 11,000 lines per sq. cm. and 50 cycles per second, by multiplying as follows:—

$$0{\cdot}73 \times 5{\cdot}2 = 3{\cdot}8 \text{ watts per kg.}$$

If the periodicity is also different, the change in the hysteresis loss will be directly proportional to the periodicity. Thus at 60 cycles per second, and 11,000 lines per sq. cm., the hysteresis loss in the above sample will be

$$0{\cdot}73 \times 5{\cdot}2 \times \frac{60}{50} = 4{\cdot}6 \text{ watts per kg.}$$

Table V.

FACTORS FOR HYSTERESIS LOSS AT DIFFERENT DENSITIES.

Periodicity in Cycles per second.	Density in Lines per sq. cm.	Multiplier by which to obtain the Loss at the Periodicity and Density in columns 1 and 2 from the Loss at 50 Cycles and 4000 Lines, *i.e.* from the Loss as deduced from the Ewing readings.
50	4,000	1·00
50	5,000	1·44
50	6,000	1·95
50	7,000	2·50
50	8,000	3·00
50	9,000	3·70
50	10,000	4·40
50	11,000	5·20
50	12,000	5·90
50	13,000	6·50
50	14,000	7·40
50	15,000	8·30
50	16,000	9·40
50	18,000	11·00
50	20,000	13·20
50	22,000	15·5

When an armature has been built of iron of which samples have been thus tested, core loss tests on the completed machine will show a loss, in watts per kg., greatly in excess of the values derived as above described from measurements on the small samples. This is not an indication that anything is wrong, but is in accordance with well-known experience. By a careful system of recording the Ewing readings, and the results on test of the completed machine, interesting values of the ratio of increase which is to be expected may be obtained. For this purpose it is well to keep records, for which, in Table VI., a convenient arrangement is suggested. It is assumed that four samples, A, B, C, and D, have been tested, and machines built from material of which A, B, C, and D are samples.

Then in the left-hand section of Table VI. should be entered the mean results of tests by the Ewing hysteresis tester on each of these samples. On the right-hand section should be recorded the losses observed on machines with armatures built of iron, of which A, B, C, and D are samples, and the mean values (M) entered up.

In an intermediate section of the table, the Ewing tests are reduced to the densities and periodicities corresponding to the machine tests. In the last column, the ratios of the machine tests to the Ewing tests are entered. It will be found that these ratios are often of the value of 2 to 3, or more. The excess is partly due to eddy current losses, which will be greater the thicker the sheets and the less carefully they are insulated from one another. The eddy current loss also varies with the degree of conductivity of the material of the sheets. In many cases, a very large part of the eddy current loss is attributable to wasteful circuits formed by the touching of the adjacent rough edges at the sides of the slots, due to poor die-work, or to too much filing of the sides of the slots. Such losses cannot be closely predetermined; but the keeping of the records above described enables a close control to be kept over them, and it should be the aim of the manufacturer to gradually reduce the ratio $\frac{M}{N}$ of Table VI. by the gradual improvement of methods of construction.

In France, an instrument similar to the Ewing hysteresis tester is employed, except that it is the magnet which is rotated.[1]

[1] Hysteresis testers with rotating magnets were built by Holden in 1895 (see *Electric Machine Design*, Parshall and Hobart, *Engineering*, 1906, pp. 11–13). Holden, however, employed electromagnets, whereas Ewing and Blondel employ permanent magnets.

Table VI.

TABLE FOR RECORDING TESTS OF RELATION OF IRON LOSS ON SAMPLE AND MACHINE.

Results on Sample.			Calculated Results for other desired Densities and Periodicities.			Machine Test.				Remarks.
Sample.	Description of Sample.	Hysteresis Loss in watts per kg. by Ewing Tester, and corresponding to Density of 4000 Lines per sq. cm. and 50 Cycles per second.	Density in Lines per sq. cm.	Periodicity in Cycles per second.	Corresponding Hysteresis Loss (N).	Density in Lines per sq. cm.	Periodicity in Cycles per second.	Iron Loss per kg. (M).	Ratio $\left(\frac{M}{N}\right)$.	

The instrument is illustrated in Fig. 11, and is known as the Blondel-Carpentier Hystérésimètre. In this instrument the density is about 10,000 lines per sq. cm. The results on any sample are reduced, by comparison of the deflection with the deflection obtained on a standard sample, to terms of the loss in ergs per cu.cm. per cycle for a density of 1 line per sq. cm.

This value, *i.e.* the hysteresis loss in ergs per cycle in 1 cu.cm. of iron, and corresponding to a density of 1 C.G.S. line per sq. cm., is called the Steinmetz Coefficient, and is generally denoted by η. As the specific gravity of sheet iron may be taken as about 7·8, it is evident that 1 kg. of sheet iron contains

$$\frac{1000}{7 \cdot 8} = 128 \text{ cu.cm.}$$

Hence, if the hysteresis loss per cycle per cu.cm. for a density of 1 line per sq. cm. is equal to η ergs, then the hysteresis loss per cycle per kg. for a density of 1 line per sq. cm. is equal to

$$128 \ \eta \text{ ergs},$$

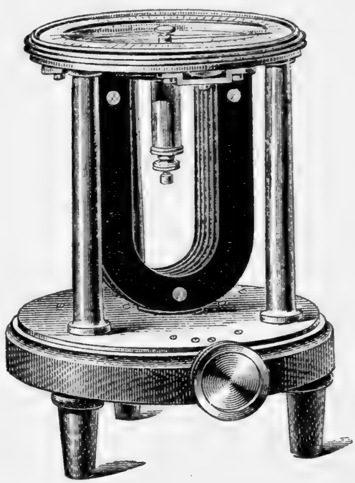


FIG. 11.—Hystérésimètre. Blondel-Carpentier.

and the hysteresis loss per kg. for a density of 1 line per sq. cm., and for a periodicity of 50 cycles per second, will be equal to

$$\begin{aligned} & 50 \times 128 \times \eta \text{ ergs per second,} \\ & = 6400 \ \eta \text{ ergs per second,} \\ & = \frac{6400 \ \eta}{10^7} \text{ watts,} \\ & = 0 \cdot 00064 \ \eta \text{ watts.} \end{aligned}$$

It would, for practical purposes, have been more convenient if the Steinmetz Coefficient had been originally defined as the loss in *watts per kg.* for a given periodicity, and for a density of 1 line per sq. cm. As, however, the practical man, when buying iron, is frequently obliged to compare data in which the hysteretic quality is guaranteed in terms of η (the Steinmetz Coefficient), there are given in Table VII., in parallel columns, the equivalent values for irons of various hysteretic qualities.

Table VII.

RELATION BETWEEN HYSTERESIS LOSS AND STEINMITZ COEFFICIENT.

The Steinmetz Coefficient, η (*i.e.* the Hysteresis Loss per c.c. in ergs[1] per Cycle, and at a Density of 1 Line per sq. cm.)	The Hysteresis Loss for a Periodicity of 50 Cycles per second and a Density of 1 C.G.S. Line per sq. cm.		The Hysteresis Loss for a Periodicity of 50 Cycles per second and a Density of 4000 Lines per sq. cm.	The Hysteresis Loss for a Periodicity of 50 Cycles per second and a Density of 10,000 Lines per sq. cm.
	Watts per kg.	Watts per ton.	Watts per kg.	Watts per kg.
·000543	·000000348	·000348	0·20	0·88
·000680	·000000435	·000435	0·25	1·1
·000812	·000000522	·000522	0·30	1·32
·000953	·00000061	·000610	0·35	1·54
·00109	·000000695	·000695	0·40	1·76
·00123	·000000785	·000785	0·45	1·98
·00136	·000000870	·000870	0·50	2·2
·00163	·00000104	·00104	0 60	2·64
·00190	·00000122	·00122	0·70	3·08
·00216	·00000139	·00139	0·80	3·52

[1] 10^7 ergs = 1 watt second.
1 watt = 10^7 ergs per second.

The erg is one of those units the significance of which most of us forget within a short time of taking up practical work. Since, however, it is sometimes employed in specifying sheet iron, it is well to recall its value.

In the Blondel-Carpentier Hystérésimètre the samples to be tested are made up from ring-shaped stampings. These stampings have external and internal diameters of 55 mm. and 38 mm. respectively. These are piled up to an aggregate thickness of 4 mm.; thus, if the sheets are 0·5 mm. thick, about seven rings will be required to make up a sample, as this gives 3·5 mm. of iron, and the remaining 0·5 mm. will be allowed for lost space. These rings should be turned, and not punched. The permanent magnet must be rotated at a speed of some 2 to 3 revolutions per second in order to obtain a steady deflection. If this deflection is, for example, 250, and if the calibration, by means of standard samples, has shown the "constant" of the instrument to be

$$0{\cdot}0000073,$$

then for the material under test, we have

$$\eta = 250 \times 0{\cdot}0000073,$$
$$= 0{\cdot}00182.$$

If we prefer to have the result in terms of the watts per kg. at a density of 4000, and a periodicity of 50 cycles per second, we can readily, by means of Table VII., ascertain this to be

$$\frac{0{\cdot}00182}{0{\cdot}00163} \times 0{\cdot}60 = 0{\cdot}67 \text{ watts per kg.}$$

The price of one of these instruments, inclusive of tested sample, is listed at £16.

It is said that for a given quality of iron, the results as given by the Blondel-Carpentier instrument are a little higher than those obtained by the Ewing instrument. This, however, is a matter of calibration, and it is not apparent that there should be any difference. Neither type of apparatus gives anything but *comparative* results, which can only be reduced to absolute values by comparison with specimens on which careful determinations of the absolute values have been made.

Brunswick and Aliamet[1] divide armature sheets into two classes:—

Class I.—Ordinary quality, for which η as measured by the Hystérésimètre varies from 0·0016 to 0·0022, and having a specific resistance of from 12 to 15 microhms per centimeter cube.

Class II.—Superior quality, for which η varies from 0·0011 to 0·0015, and with a specific resistance as high as 45 microhms per centimeter cube.

[1] *Construction des Induits à Courant Continu*, p. 18.

Sheets of this latter quality are stated by these authors to be obtained by treating steels containing a small percentage of aluminium or silicon (2 to 4 per cent.). This superior material can only be obtained at a very substantially higher price as compared with the ordinary material. It is, moreover, not so necessary in armature construction to obtain an exceedingly low iron loss, as it is in transformer construction.

The property of high specific resistance, while it does not, of course, affect the hysteresis loss, affects the other component of the iron loss, namely, the loss due to Foucault currents; and hence progress in this direction is of great importance.

The writers above alluded to, in describing the conditions controlling French practice, state the customary composition of armature plates to be an extra-soft steel containing about 0·03 per cent. of carbon, and often small quantities of silicon or aluminium. It would appear that, in France, sheet iron for armature construction is most generally delivered in plates 0·80 metres wide by 1·65 metres long. Plates as wide as 1·2 metres may be obtained, but the price will be some 30 per cent. to 35 per cent. higher than that of plates of the former dimensions.

Referring to plates of a thickness of 0·4 mm. (apparently the most customary thickness employed in France), Brunswick and Aliamet state that Class I.[1] plates of a width of 0·85 metre cost about £15 per ton, as against about £20 per ton for widths of 1·20 metres.

Allusion has been made above to the circumstance that instruments, such as those of Ewing and of Blondel, only indicate the order of magnitude of one component of the iron loss, giving no indication of the other component loss due to Foucault currents. The quality of the iron as regards Foucault current loss may be readily ascertained by measuring the resistance of strips of determined dimensions. It is desirable to have as high a specific resistance as practicable.

In Germany, it has been deemed preferable to employ methods of measurement of the quality of sheet iron which give the total iron loss — *i.e.* methods which do not distinguish between the hysteresis loss and the Foucault current loss. The Richter apparatus, already described on p. 16, is an instance of this practice. Another instance is afforded by the Epstein apparatus, which, in fact, is the apparatus to which specific allusion is made

[1] Class II. plates at present cost from two to three times as much as Class I. plates.

in the Standardisation Rules for the Testing of Sheet Iron, drawn up by the Verband Deutscher Elektrotechniker. These rules read as follows:—

1. The total loss in the iron shall be measured by means of a watt-meter on a sample made up of at least four different plates. The sample shall weigh at least 10 kgs., and the loss in watts per kg. shall be determined at a given temperature for a maximum induction of 10,000 lines per sq. cm. and a periodicity of 50 complete cycles per second.

2. As normal thickness, shall be taken 0·3 mm. and 0·5 mm.; deviations from the normal thickness shall not exceed 10 per cent. (By this is meant deviations of appreciable extent, and not pitted places or small protuberances which are unavoidable in the manufacture of sheet iron.)

3. The measurements shall be made on a magnetic circuit composed exclusively of iron of the quality to be tested, and built in accordance with the conditions here set forth.

4. As specific weight of the iron, 7·77 shall be taken in all cases where more precise data is not available.

5. In disputed cases, the determination of the Physical-Technical Imperial Institute shall be accepted, and the determination shall be made at an iron temperature of about 30° Cent. when no other temperature has been specified.

Specification for the Test.

As normal form for determining the iron loss, a uniformly-wound ring may be employed. As, however, for practical conditions, certain disadvantages are associated with the use of a ring, the Standardising Commission for Iron Testing recommends that either the apparatus of Epstein or that of Mollinger shall be employed. In guarantee determinations, it is recommended that the iron loss be determined by means of one of these two types of apparatus.

For tests by means of the Epstein apparatus, the following instructions should be observed:—

The magnetic circuit is constructed of four cores, each having a length of 500 mm., a breadth of 30 mm., and a weight of at least 2·5 kgs., thus making a total weight of at least 10 kgs. for the four cores. The individual sheets are insulated from one another by Japanese paper in such a manner that they are at no point in contact with one another. The four cores constitute a rectangular circuit, as shown in Fig. 12, and are secured in position by wooden clamps at the four corners. At the butt-joints, they are separated from one another by presspahn of 0·15 mm. thickness. In building together the circuit, care must be taken that the cores fit well with one another: as indications of which, are the deadening of the noise when magnetised, and the obtaining of a minimum deflection on the ammeter in the magnetising circuit.

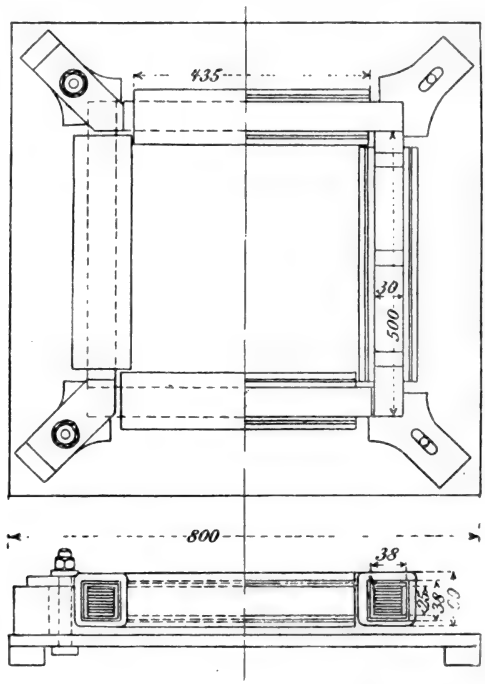


FIG. 12.—Sectional Drawing of an Epstein Tester.

The magnetising coils are constructed on presspahn bobbins, with internal dimensions of 38 mm. × 38 mm. and a length of 435 mm. Each of the four bobbins contains 150 turns of copper of a cross section of 14 sq. mm. It is suggested in the rules that the winding may conveniently consist of two edge-wound conductors measuring 2 × 3·5 mm. and wound in parallel.

Originally it was thought preferable to build up these Epstein samples to a weight of 20 kgs., but this weight has ultimately been reduced to 10 kgs., which is now standard. A photograph of a wound sample is shown in Fig. 13. In Fig. 14 is shown the iron-testing room of a rolling mill. The Epstein sample may be seen on the table at the right of the figure.

A testing-room fitted out with a Richter apparatus which is capable of testing, at one time, four complete sheets measuring 1 metre × 2 metres, is shown in Fig. 15. This installation is on the premises of a rolling mill.

The provision to electrical manufacturers, of punchings completely finished, including the slots, has been undertaken in England by certain firms; but the largest manufacturers of dynamo-electric machinery do their own punching work.

The most customary standard size in which sheet steel for armatures is delivered, is in plates measuring 1 metre × 2 metres.

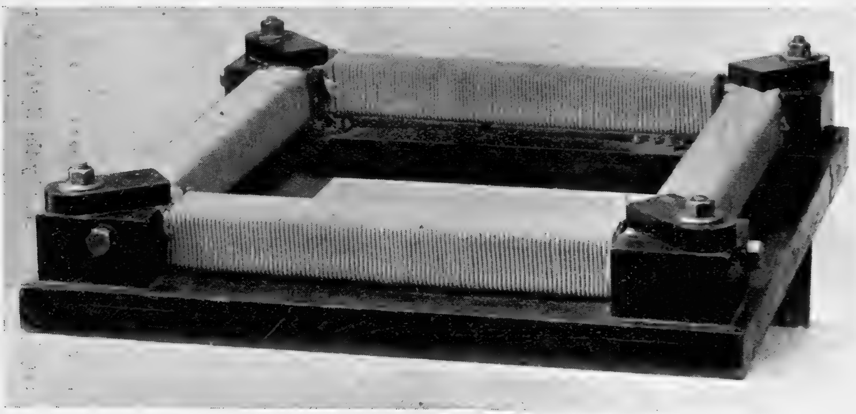


Fig. 13.—Photograph of Epstein Iron Tester.

Plates of larger dimensions are generally only supplied at higher prices, and a longer time is required for providing them. It has thus become fairly general practice to build up armature cores of larger diameters than 1000 mm., out of segments whose maximum dimensions do not exceed the dimensions of sheets of this standard size. Frucht[1] suggests that 990 mm. be standardised as the largest diameter of armature in which complete discs shall be employed.

In Figs. 16 to 21 are drawn, to a scale of 20:1, six such normal plates, on which are indicated the outline of armature plates which may serve as instances of standard practice.

[1] *Zeitschr. des Vereines Deutscher Ing.*, 30th May 1903, p. 769: "Die Herstellung der im Dynamobau gebrauchten Bleche."

Fig. 16 shows a blank plate 1000 mm. × 2000 mm.

In Fig. 17 there are outlined two discs of 990 mm. diameter showing the largest which can be cut from the standard sheet.

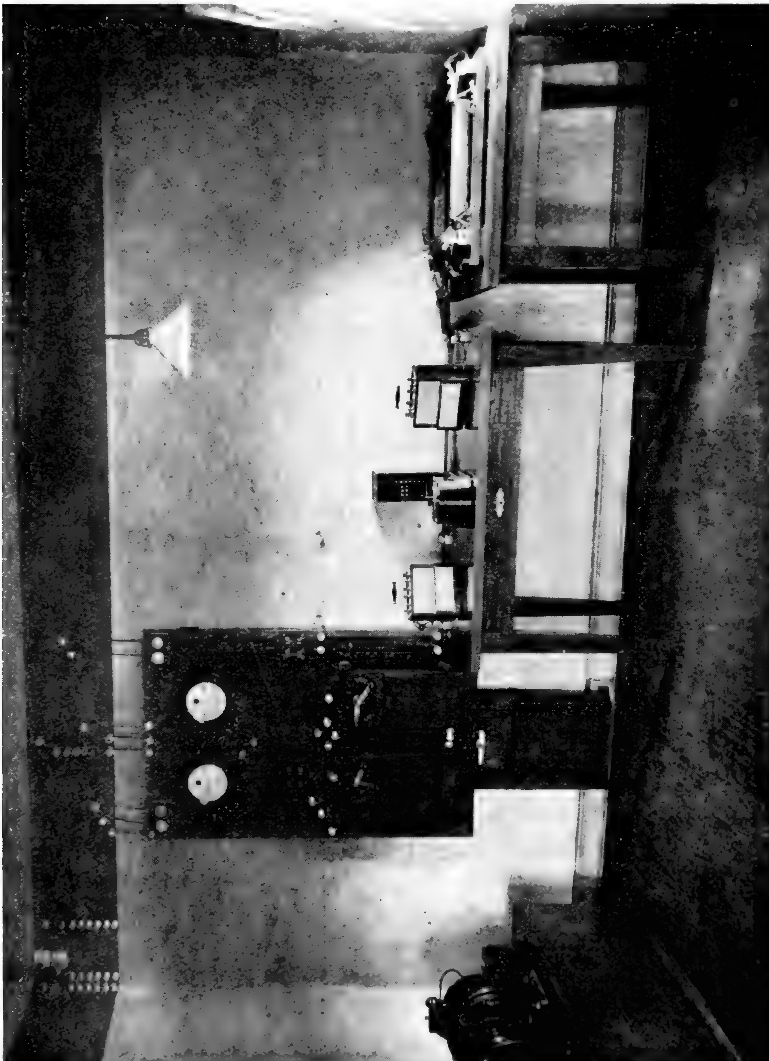


Fig. 14.— Room equipped for Testing by the Epstein Apparatus.

Fig. 18 shows the sheet well utilised for core discs of about 490 mm. diameter. In this case the sheet would be cut down the centre, at AB, in a circular cutter shearing machine, and the long strips fed into the stamping press one at a time. The

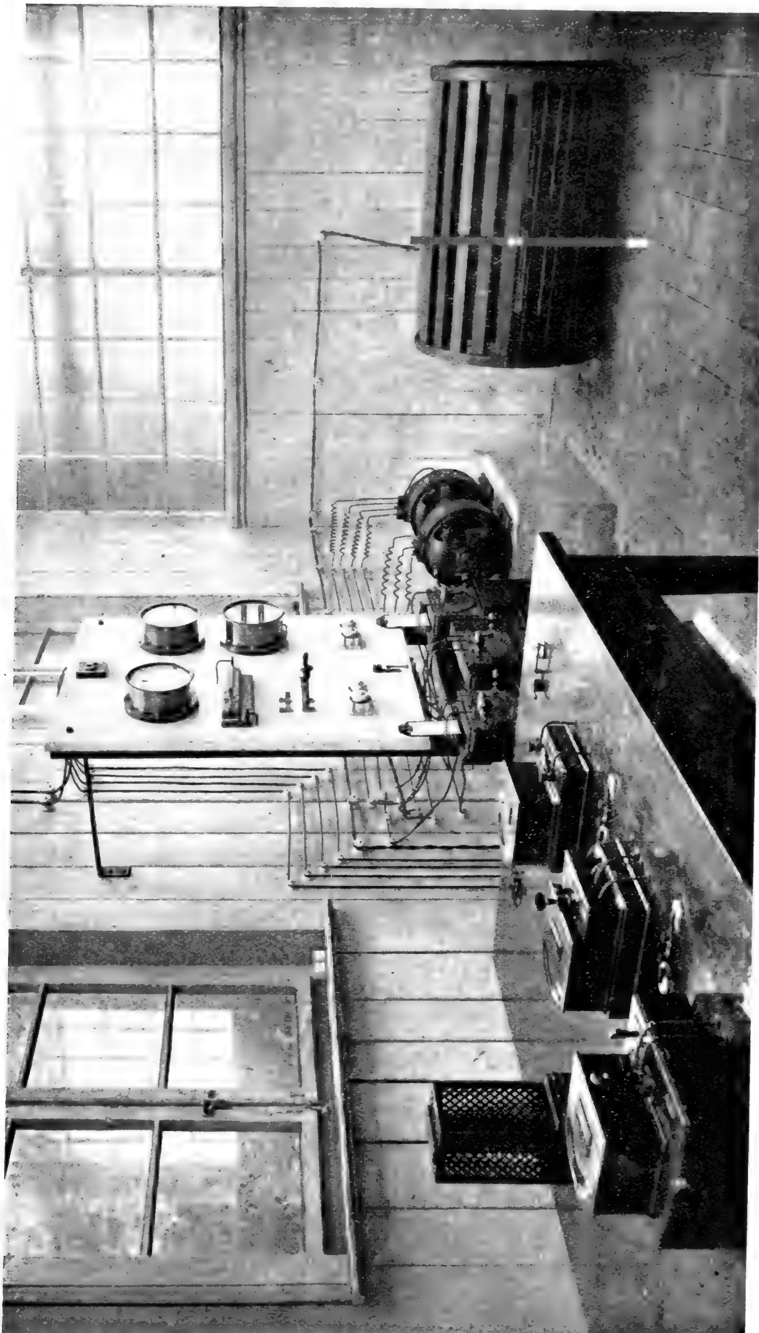


FIG. 15.—Room equipped for Testing by the Richter Apparatus.

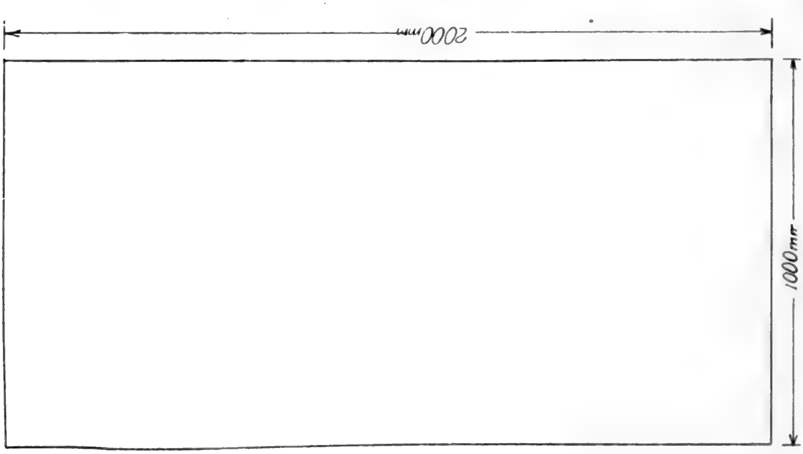


FIG. 16.

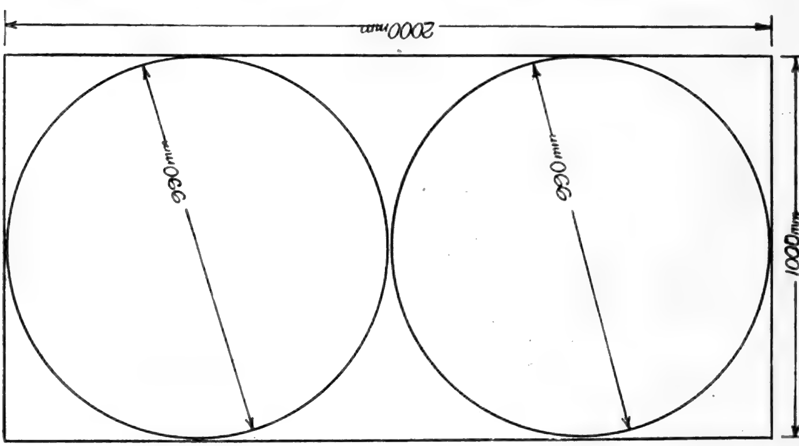


FIG. 17.

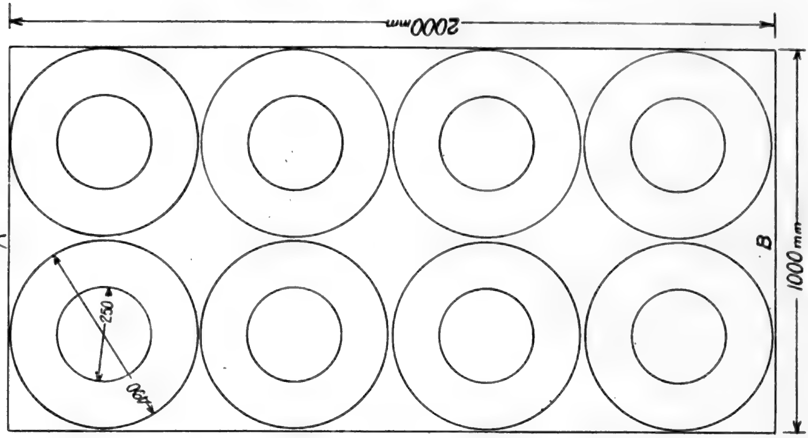


FIG. 18.

Diagrams showing the most economical arrangement of various types of Stampings from Standard Sheets.

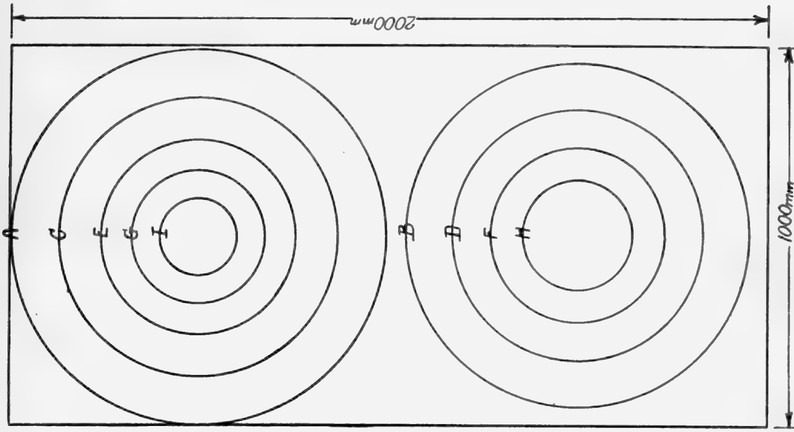


Fig. 21.

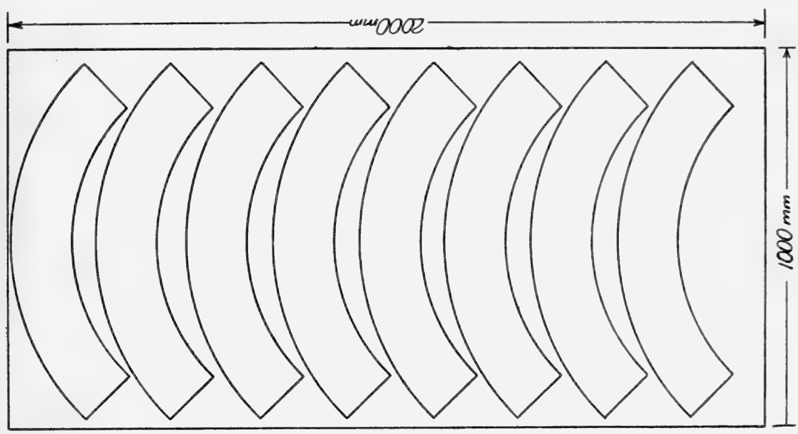


Fig. 20.

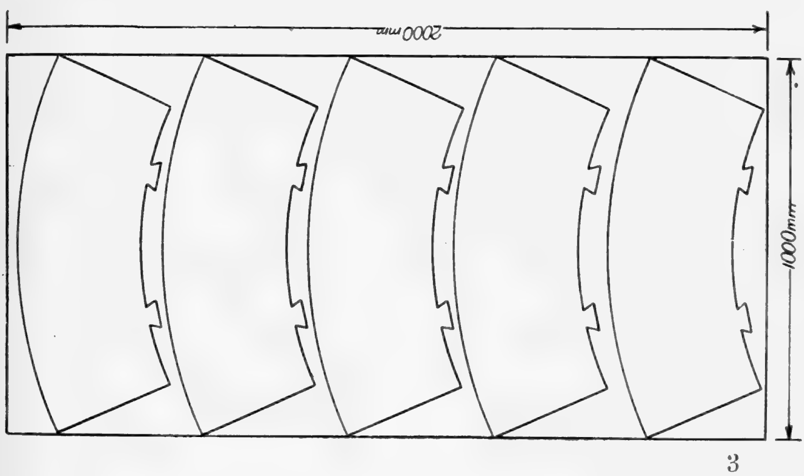


Fig. 19.

Diagrams showing the most economical arrangement of various types of Stampings from Standard Sheets.

inside parts left after cutting these stampings are subsequently used up for the making of core discs of smaller diameter.

Figs. 19 and 20 show typical stampings for large armatures, the minimum waste being obtained by progressing down the sheet as shown.

Sometimes a series of external and internal diameters is so standardised for a set of designs as to greatly minimise the waste in punching. In Fig. 21 is given an instance where, by means of a double series of diameters, A, C, E, and B, D, F, etc., the sheets are almost entirely used up. Diameter B is chosen about midway between A and C, and so on with the other diameters. From these two sets of diameters may be obtained thirteen different combinations, half of this number being of narrow depth radially and half of wide radial depth. These possibilities are shown in Table VIII.

TABLE VIII.

SIZES OF STAMPINGS OBTAINABLE FROM TWO SETS OF DIAMETERS IN FIG. 21.

No.	External Diameter.	Internal Diameter.	
1	A	C	Stampings of Small Radial Depth.
2	B	D	
3	C	E	
4	D	F	
5	E	G	
6	F	H	
7	G	I	
8	A	D	Stampings of Great Radial Depth.
9	B	E	
10	C	F	
11	D	G	
12	E	H	
13	F	I	

Frucht alludes to the difficulty of obtaining a smooth, clean surface on the sheets, and at the same time retaining good magnetic quality; for the smooth surface is only obtained by a greater number of passages of the sheets through the rolls, and with each passage the sheets become harder and magnetically inferior. Nevertheless, unless the plates are rolled fairly smooth, there will be an undesirably high percentage of space lost lengthwise between the core flanges.

Formerly it was thought desirable to anneal the plates after punching, and this is doubtless the ideal method; but it involves considerable expense, and is nowadays rarely regarded as necessary in the case of armature core plates, and the sheets are generally purchased already annealed.[1] The annealing, as has already been stated, should be from as high a temperature as practicable without causing the plates to stick together.

In the operations of punching out the discs and the slots from the plates as delivered, the surface should be moistened in advance of the punch (in the case of index die-work) by applying turpentine with a brush. In the case of a compound die, the turpentine must be applied over the portions to be punched out. Turpentine has great advantages over oil and over soap-and-water, since no subsequent cleaning of the plates is required, as would be necessary were oil or soap-and-water employed. In former times, when these latter materials were used, the plates were subsequently cleaned by immersion in a hot bath of dilute caustic soda. Of course, when the plates are annealed after punching, they are cleaned in the process. Some firms coat the sheets, prior to punching, with thin paper, to insulate them from one another; but it is generally conceded that the application, after punching, of coatings of insulating varnish, is fully as satisfactory a method and involves less expense. In some cases of paper-insulated armature cores which were taken apart after a few years of service, the paper was found in an advanced stage of disintegration, and the core discs had become oxidised under the influence of exposure to the paste with which the paper had been applied. The crumbling of the paper would appear to be due to the combined influences of vibration, heat, and pressure.

Let us now return to the consideration of the 1 metre × 2 metres steel sheet (Fig. 16), as originally received. Unless it is to be used for discs of nearly 1 metre diameter, or for segments nearly 1 metre wide, it will often be found convenient to first cut it up by shears of some such type as the tool illustrated in Fig. 22, into smaller sheets of suitable dimensions. Whether these sheets shall next be punched at one operation by a compound die, or whether this shall be done in several steps, is a question involving the disadvantage of the very expensive compound die on the one hand, and the

[1] Plates for transformer cores are generally annealed again after punching, owing to the greater importance of minimum core loss.

disadvantage of greater expenditure for time and labour on the other hand. It thus usually resolves itself into a question of whether enough plates will be required (as would be the case with standard designs built for stock) to justify the outlay for the compound die. The compound die has up to recently been considered indispensable for the highest class of work. With the most modern machinery, however, equally good results may be obtained by means of index die-work. Even for discs of quite small diameter, the cost of a compound die is a very appreciable item;

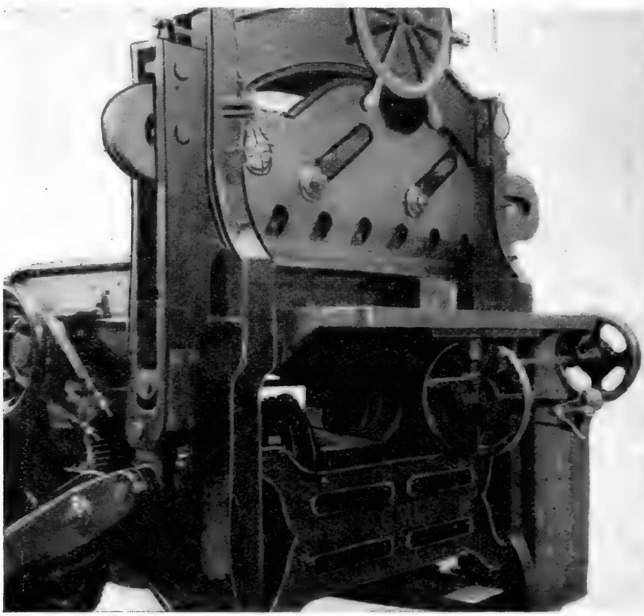


FIG. 22.—Power Shears for cutting Sheet Steel prior to punching Armature Core Plates.

and for large discs or segments, it runs into hundreds of pounds. Another consideration affecting the decision, is that of practicable sizes of presses. A press with a capacity for providing a pressure of over 200 tons may be required in stamping out slotted discs with a diameter of one metre, by means of a compound die.

Brunswick and Aliamet[1] give the following rule for obtaining the total pressure for which the press must be capable, in order to punch a disc or segment of given dimensions:—If t = thickness

[1] *Construction des Induits à Courant Continu* (Gauthier Villars; Maison et Cie.), p. 69.

of the plate in mm., and if p = perimeter of the cut, also in mm., then $45 \times t \times p$ = required pressure (minimum) in kgs. Thus, to cut from a sheet of 0·5 mm. thickness one of the plain discs of 990 mm. diameter (Fig. 17), there would be required a pressure of at least

$$45 \times 0{\cdot}5 \times 990 \times \pi = 70{,}000 \text{ kgs. (70 tons).}$$

If, instead of a plain disc, it were required, by means of a com-

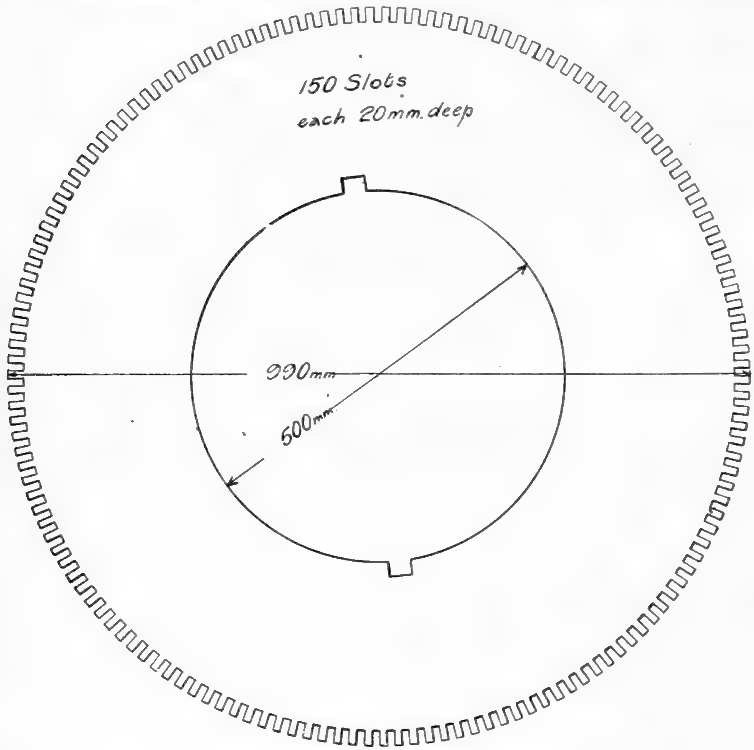


FIG. 23.—150-Slot Armature Stamping from Compound Die.

pound die, to punch from 0·5 mm. thick sheets, the discs shown in Fig. 23, which have an external diameter of 990 mm., an internal diameter of 500 mm., and 150 slots, each 20 mm. deep, then the perimeter amounts to approximately

$$990 \times \pi + 500 \times \pi + 300 \times 20$$
$$990 \times \pi = 3110$$
$$500 \times \pi = 1570$$
$$300 \times 20 = 6000$$
$$\text{Total perimeter} \quad = 10680 \text{ mm.}$$

This would require a pressure of at least

$$\frac{45 \times 0{\cdot}5 \times 10700}{1000} = 240 \text{ tons.}$$

Of course the quality of the material, and the design and condition of the disc and the tool, greatly affect the required pressure.

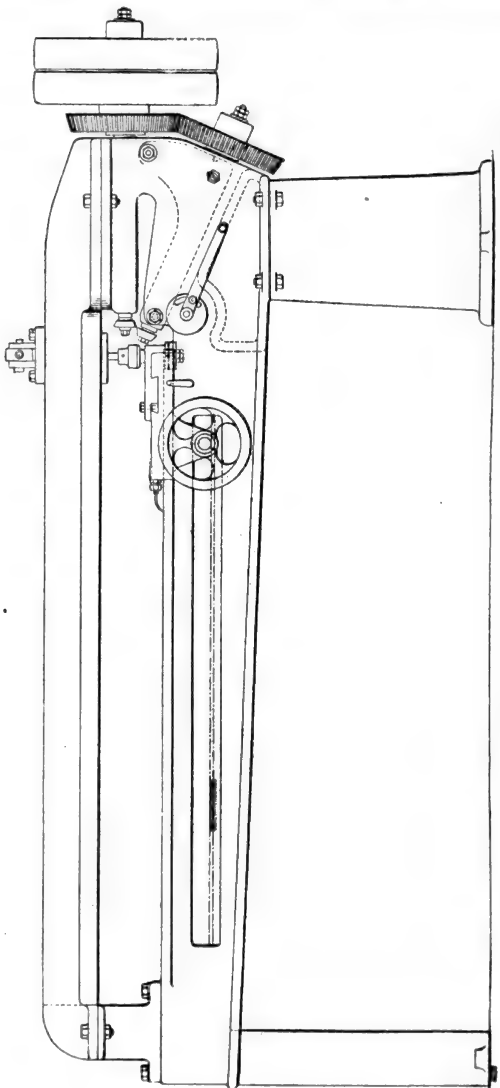


Fig. 24.—Armature Disc and Ring Cutting Machine.

We may illustrate, by an example, another consideration controlling the choice of method to be employed. The compound die for the stator punchings of a certain 600 h.p. induction motor cost some £200. Three such motors were to be built, and it was estimated that to punch out the slots, one at a time, by index dies by means of two automatic presses, would have taken about twelve weeks for the 1,500,000 slots. This would have made it impracticable to deliver the machinery within the required time without buying additional presses.

In many instances, however, the use of automatic punching machines with index dies is suitable, and will in this treatise first be dealt with. The discs may be cut by some such type of circular shear as that illustrated in Fig. 24. This machine is by Messrs Daniel Smith & Co.,[1] and will divide off annular rings of any width up to 330 mm. (13 in.), and is capable of cutting blanks and rings up to 1520 mm. (60 in.) in diameter in all thicknesses up to 1·65 mm. diameter (No. 16 B.W.G.). The machine consists of a framework, at one end of which revolving disc cutters are placed, which are driven by gearing, as shown. The cutters are not placed in the same plane, but are inclined to each other at a considerable angle, their spindles being connected through bevel gearings. The top beam gives stiffness, and on it there is placed an instantaneous eccentric lever pallet grip, by means of which

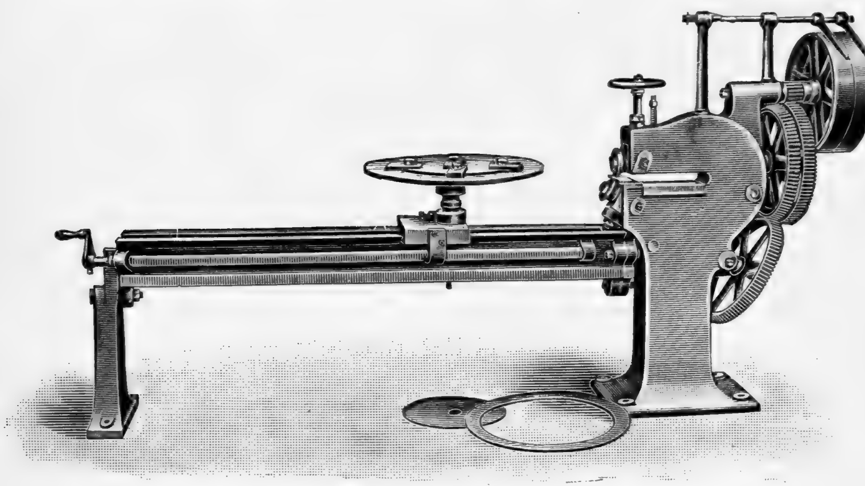


FIG. 25.—Geared Rotary Shears for Armature Discs and Rings.

blanks without central holes may be formed; while, in the saddle, which travels on the lower slide, there is a rotary stud for taking discs which have been previously pierced in a press. The saddle is moved by means of the hand-wheel shown in front of the bed; and in the top beam there is a longitudinal slot which allows the gripping pallets to readily follow the saddle.

A less elaborate type of circular shear for power drive, as supplied by Messrs Neville Bros., is shown in Fig. 25; and a machine to be manually operated and only suitable for small discs, in Fig. 26. This latter machine is by the E. W. Bliss Co., as is also the larger machine for power drive shown in Fig. 27.

[1] The description of this machine is taken from p. 117 of *Engineering*, for 27th January 1905.

Frucht, in the article above referred to, thus describes the process of making small armature discs: In a plate of suitable size, as shown in Fig. 28, a central hole is punched, as also two

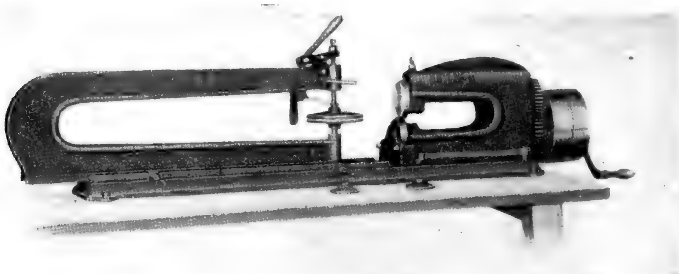


FIG. 26 —"Bliss" Circular Shears.

slots which shall ultimately serve as key-ways. Although two slots are illustrated, good practice has shown that only one key-way suffices in such a case. Frucht showed four key-ways. The

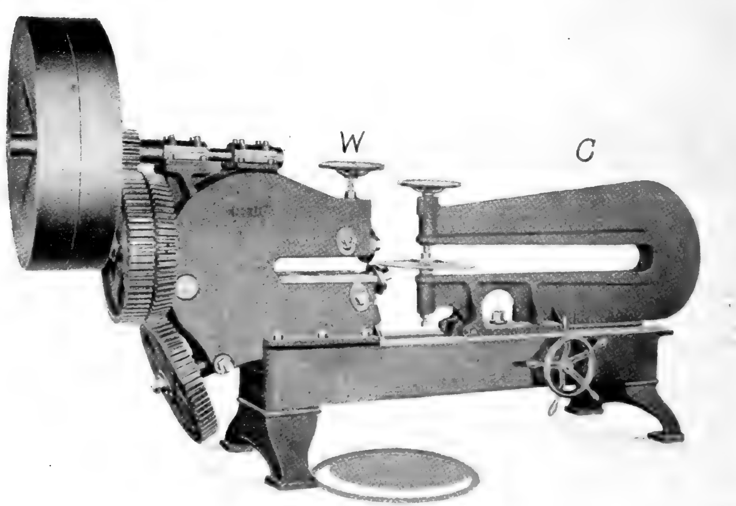


FIG. 27.—Circular Shears with Angular Cutter Shafts.

plate is then mounted in the circular shears, as illustrated in Fig. 27, which, however, shows the plate after the completion of the operation of cutting it circular. The upper knife may be raised and lowered by means of hand-wheel W. If only the small central

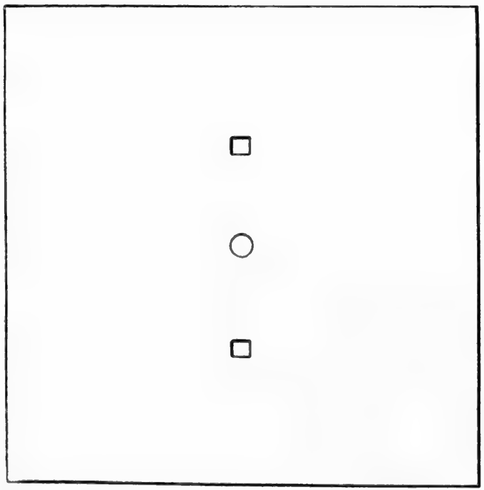


Fig 28.

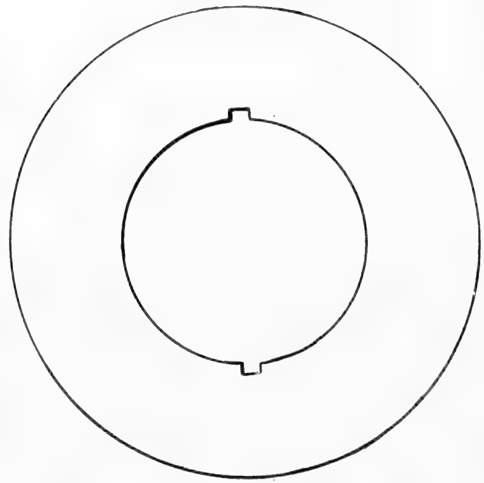


Fig. 29.

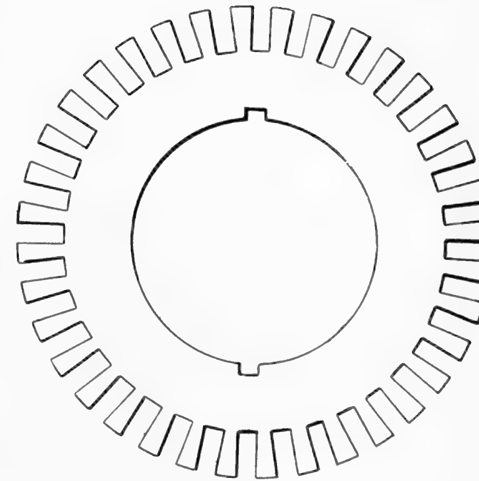


Fig. 31.

Diagrams showing process of stamping Armature Core Plate.

hole is required, then the operation of punching it out may be combined with the process of clamping the disc, in which case the hand-wheel above the centre of the disc is replaced by a lever, operating both punch and clamp. But in such a case as the plate of Fig. 28, where two additional slots are required, the middle hole and these two slots are most conveniently slotted out beforehand on an eccentric press. To produce from the plate of Fig. 28 the annular disc of Fig. 29, first the outer and afterwards the inner circumference must be cut, thus necessitating two settings of the carriage, C, on the tool-bed.

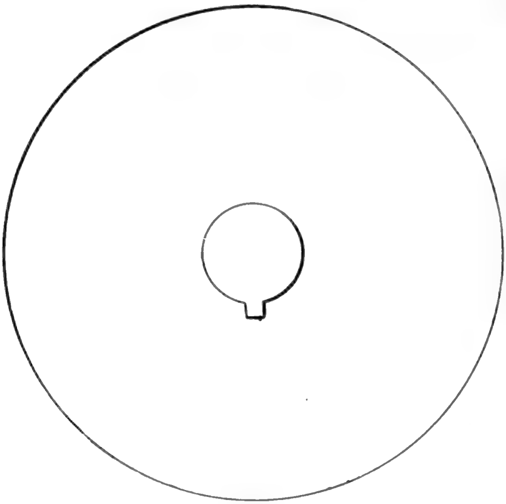


FIG. 30

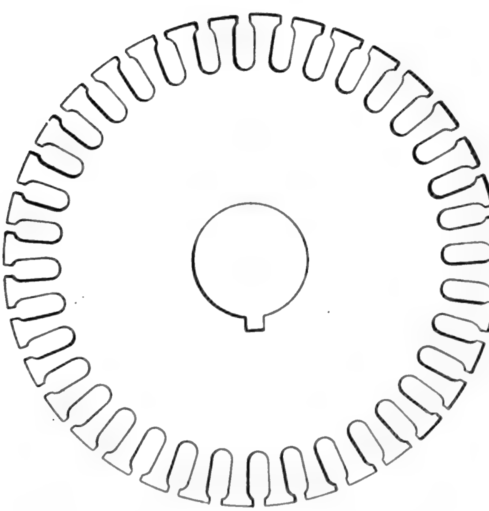


FIG. 32.

Diagrams showing process of stamping Armature Core Plate.

It is impracticable, by means of circular shears, to cut circles of less than 100 mm. diameter; and hence for a disc, such as that shown in Fig. 30, the central hole and key-way should be stamped out beforehand. From discs such as those of Figs. 29 and 30, the next operation is to punch out slots on the periphery, thus obtaining the finished armature core plates shown in Figs. 31 and 32. When, as in the process we are now describing, the slots are punched out one at a time (or, in some cases, two or more adjacent slots at a time), a finger die is employed. One form is described by Brunswick and Aliamet by means of a sketch, which we reproduce in Fig. 33. The principal parts to which we should direct our attention are the punch, P, and the die, D. The punch, P, is of equal section throughout its length; but the die, D, diverges so as to avoid wedging, while at the same time permitting of a very exact fit at the upper surface on which rests the plate to be punched. Frucht recommends that, in order to make a clean-edged cut, the punch should be smaller than the size of the slot to be cut, to the extent of one-eighth of the thickness of the plate, and that the aperture in the die should be an equal amount larger than the size of the slot to be cut. The illustration in Fig. 33 relates to the so-called French type, which is characterised by the guiding of the punch, P, by means of the guide, G. The plates must be inserted between the lower surface of G and the upper surface of the die D. This type is inconvenient as regards the less ready manipulation of the plate in the restricted space between G and D, but it affords a very exact guidance to the punch P, right close down to the surface to be punched. A slight modification of the so-called "French" type is shown in the punches of Fig. 34, where will be seen at the side of the punches, and mounted rigidly with them in the same blocks, guiding rods so designed as to ensure exactness in the movement of the punch, thus avoiding the necessity for passing the punch itself through guides.

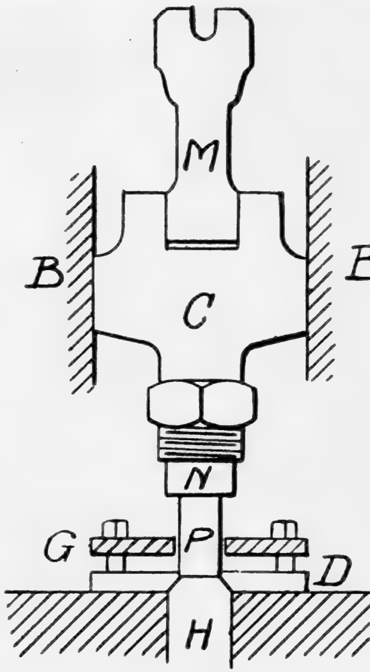


Fig. 33.—Detail of Punch and Die.

M, Connecting-rod for Driving.
B, B, Guide of Slide Block C.
N, Punch Holder.
P, Punch.
D, Die.
G, Guide of Punch.
H, Bed of Punching Machine.

The alternative and generally preferred method, employs the so-called "German" type. In this type the punch is short, and after having perforated the plate, does not pass an appreciable distance beyond. As applied to a compound die, the construction is illustrated in Fig. 35. The principle of the "German" type is shown in Fig. 36. The punch is mounted firmly in a solid piece, and can thus only penetrate to a short distance below the upper surface of the die.

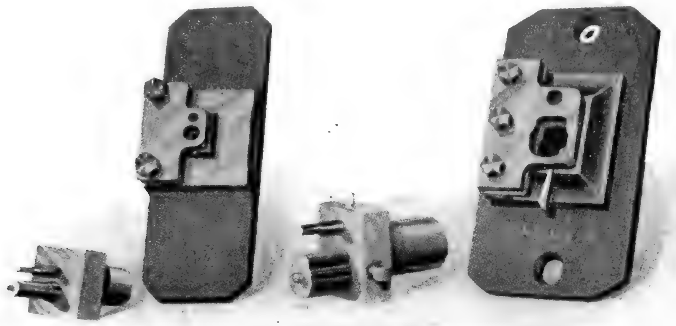


Fig. 34.—"Bliss" Double Die.

When slots are to be provided on the inner periphery of a disc, as in the case shown in Fig. 37, it is sometimes the practice (when an index die is employed) to first punch the slots, and afterwards cut out the centre on circular shears. Fig. 38 illustrates how, without making another punch, a deeper slot may be obtained than

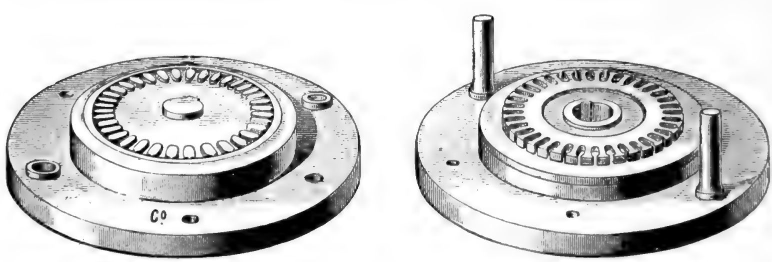


Fig. 35.—Compound Die for Armature Disc.

that for which the punch has been proportioned. Such makeshifts are, of course, only economical in special contingencies, and involve two operations with consequent loss of time.

Fig. 39, reproduced from Frucht's article, illustrates a punch which cuts both slot and a corresponding portion of the periphery at each stroke. Frucht recommends this as far preferable, largely on account of greater exactness in the cutting of the periphery than is obtainable by circular shears, and states that it is particularly appropriate for induction motors, which, owing to the small radial depth of the air-gap, require very exact die-work. He further points out that when such work is done on circular shears, with the consequent lesser exactness, difficulties are sometimes encountered in subsequently turning down the core on a lathe to the precise required dimensions. These difficulties relate to the liability of bending the teeth, and, in the case of nearly closed slots, tearing the tips of the teeth. The bending of the teeth may be avoided by inserting temporary keys completely filling the slots, prior to the turning. The tearing of the teeth may be avoided by first punching completely closed slots, then turning the core to the precise dimensions, and finally milling out the slot openings. This last step in the operation introduces the liability to increased eddy current loss. This is of minor importance on the rotors of induction motors, but is to be avoided in the stators. In fact, in the case of the stators of induction motors, compound dies are greatly to be preferred.

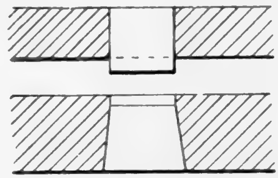


FIG. 36.—German Type Die.

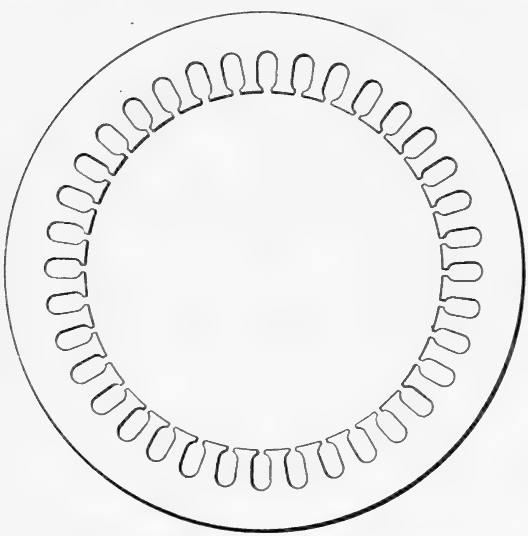


FIG. 37.—Disc with Slots in Inner Periphery.

Frucht, however, has obtained excellent results with the process employing the punch shown in Fig. 39. He states that by using good, smooth plates, and by ensuring that slots of different plates but corresponding to a given position of the index of the punching machine shall be over one another in the assembled core, he has for years, without doing any tool-work or filing on the assembled core, successfully employed the following scale of radial depths of air-gap and diameter at air-gap:—

TABLE IX.

FRUCHT'S VALUES FOR AIR-GAP DEPTHS.

Radial Depth of Air-gap in mm.	Diameter at Air-gap.
0·4	Up to 200 mm.
0·5	„ 400 „
0·75	„ 600 „
1·00	„ 800 „

The writers do not, however, care to employ so small a radial depth of air-gap, and their own experience has shown them that it is by no means essential to good results.[1]

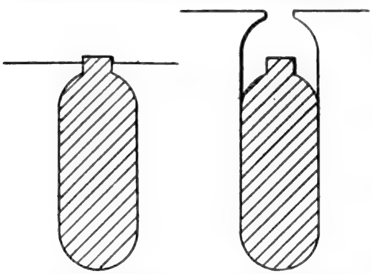


FIG. 38.—Punching extra deep Slot.

In the case of the rotors of induction motors, plates considerably thicker than 0·5 mm. might quite properly be used; and this would not only decrease their first cost, but, inasmuch as it would decrease the number to be handled, the labour cost would also be less. But since the rotor core plates can be made out of the otherwise wasted centres punched out from the stator core plates, this practice is generally followed, and the same thickness of sheet is generally employed for stator and rotor; in fact, the very best results are obtained by making a compound die to punch out both stator and rotor discs, complete with slots, at a single operation. It is also sometimes the practice to punch out both stator and rotor slots at a single operation, and then to cut first the external diameter of the stator; secondly, the internal diameter; and finally the internal diameter of the rotor, on circular shears. Some discs, thus prepared, are shown at the foot of the index press in Fig. 40.

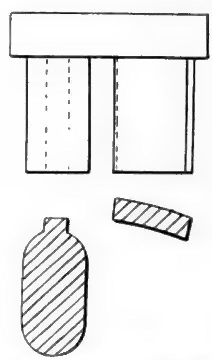


FIG. 39.—Die for cutting Slot and Periphery.

Obviously, there still remains the further operation of turning down the rotor core on a lathe subsequent to assembling. Index presses of various firms are illustrated in Figs. 40, 41, 42, and 43. While varying greatly in detail, the underlying principle is that each stroke of the punch is followed by an angular motion of the clamps holding the disc or

[1] A Table of the writers' values for induction motor air-gaps will be found on p. 105, Chap. VI.

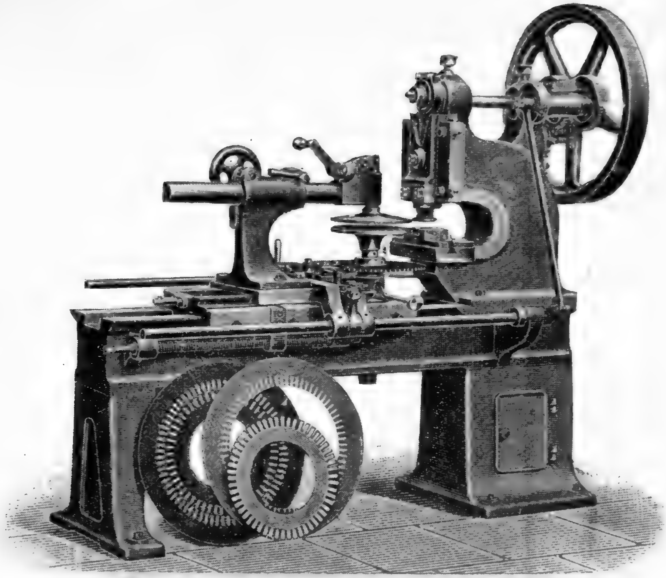


FIG. 40.—Automatic Index Press for Slotting Armature Discs. Erdmann Kircheis.

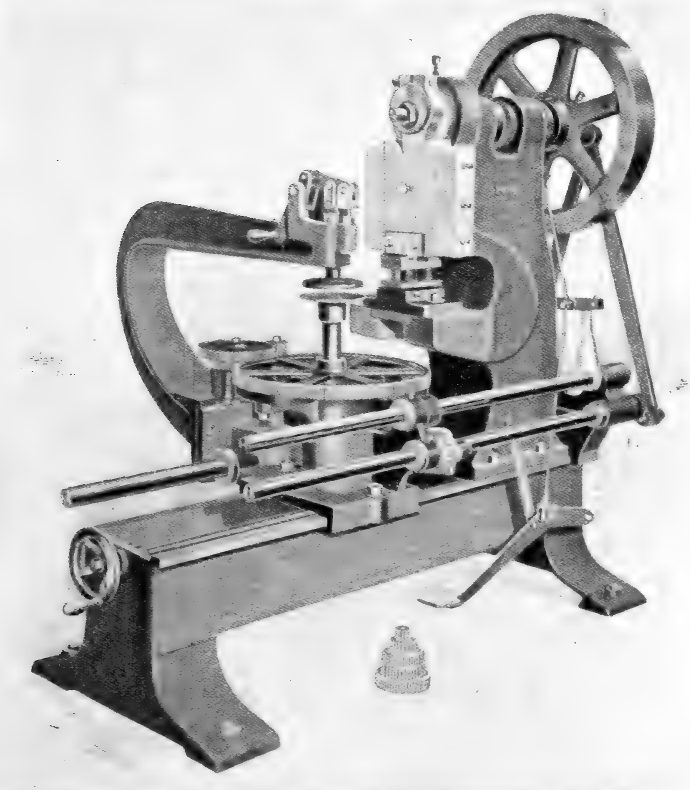


FIG. 41.—"Bliss" Automatic Armature Disc-notching Press.

segment of a disc. This angular motion is adjustable by index plates, a number of which are supplied with the press. These are so designed that, with a minimum number of index plates, a maximum variety of numbers of slots may be obtained.

The mechanical movements must be designed with a minimum of inertia and of back-play, and must be capable of very rapid work.

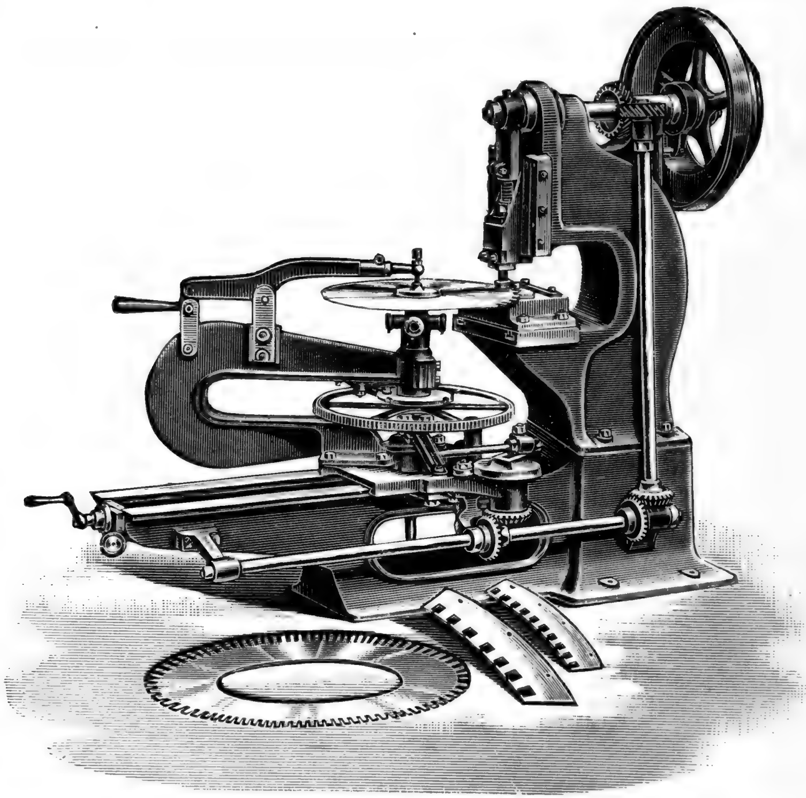


FIG. 42.—The Stoll Automatic Armature Disc-notching Machine.

A type of circular shear built by Messrs Zeh & Hahnemann is illustrated in Fig. 44. This machine is especially suitable for cutting the segmental core plates for armatures of very large diameter. To meet conditions where, in the case of large armatures with segmental core plates, it is desired to avoid going to the expense of a compound die, Messrs Zeh & Hahnemann have developed a set of machines, which have been described on p. 180 of the *American Machinist* for 24th February 1906, from which the following has been abstracted:—

The machines are especially adapted to work in which the dovetails by which the segments are secured to the armature frame (or spider) are notched out of the stamping, as in the case

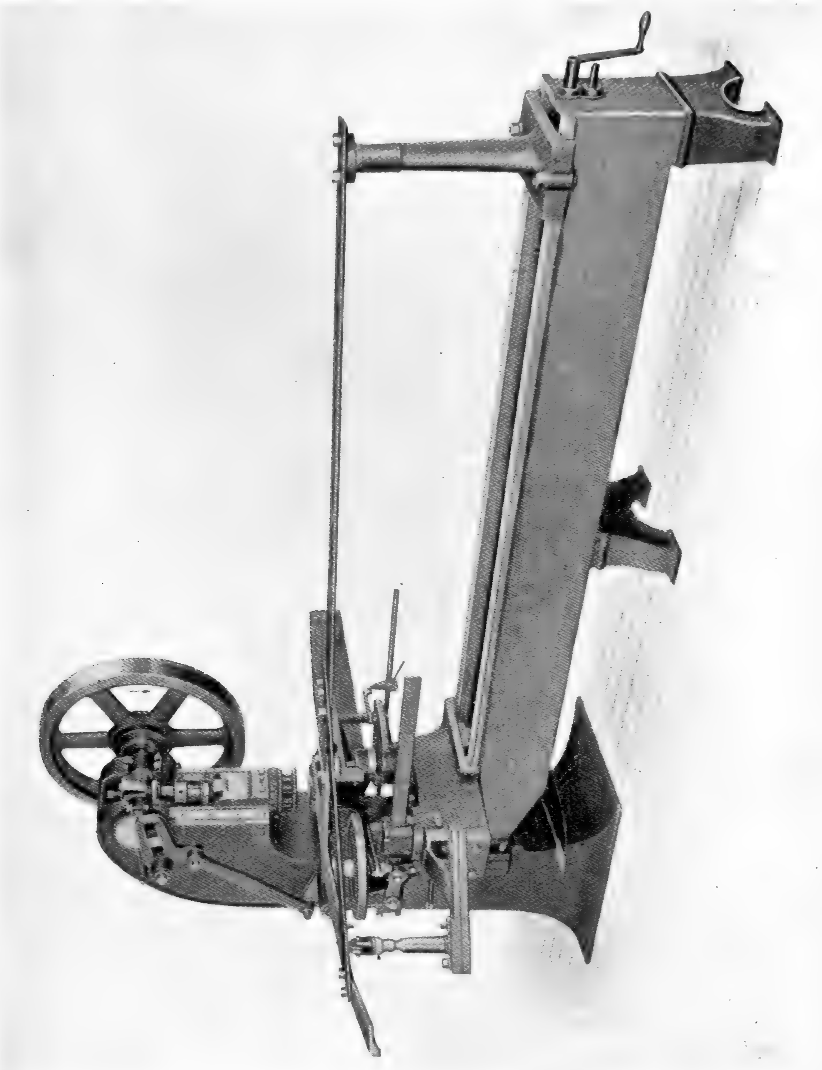


FIG. 43.—Armature Segment Notching Press. Bliss Co.

of the lamination illustrated in Fig. 49 of this chapter, as in this case the material can be cut to considerably better advantage than otherwise.

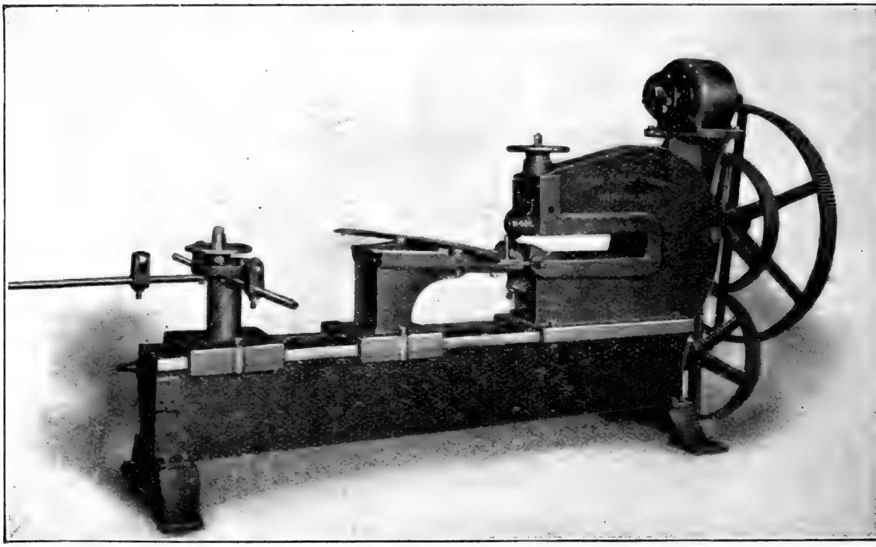


FIG. 44.—Circular Shear with Segment Attachment. Zeh & Hahnemann.

The full sheet of metal first passes a double-crank power press (Fig. 45), which punches the holes that later form the dovetail notches, and also cuts the long radial slits for the ends of the segments, as indicated in Fig. 46. The dies for these notches, as well as the slitting knives, are adjustable within wide limits, and can readily be set by means of a suitable template. Plain gauges are provided to space properly the succeeding cuts.

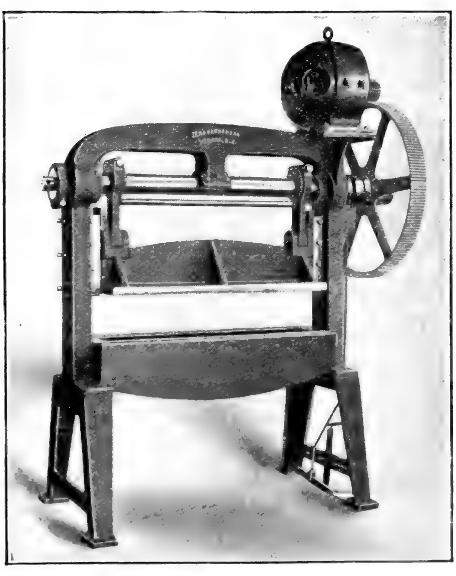


FIG. 45.—Double Crank Press. Zeh & Hahnemann.

The sheet thus prepared, next passes through the circular shear with segment attachment, already shown in Fig. 44. This cuts the segments apart and finishes the periphery, as shown in Fig. 47.

The segment attachment comprises a sector of suitable form, which is guided by anti-friction rolls. The sheet to be cut is fastened to this sector and guided by it in a circular path past the cutters, the guiding rolls being near the cutters to prevent vibration. The same sector may be used, within certain limits, for varying radii, as the gauging parts may be fastened to adjustable arms, thus allowing work to be cut to any radius, with a limited number of sectors.

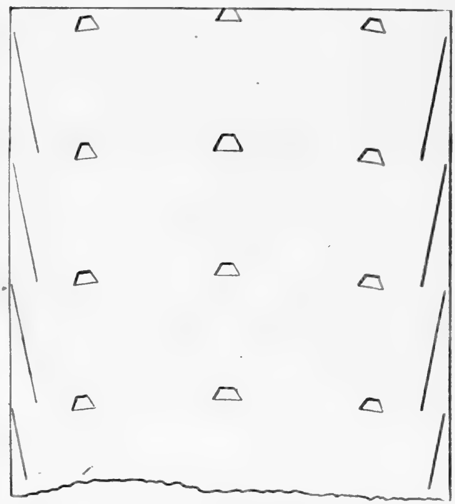


Fig. 46.—Drawing showing Sheet punched for Dovetail Notches and Slot for Segment Ends.

The segments prepared in this manner are now ready to be slotted and trimmed on the inside. The machine for punching the slots is illustrated in Fig. 48. It has a guiding sector similar to the segment shear; but this sector has cut in its periphery, notches in which a feed-pawl, actuated by the press, engages, thus feeding the sector with the attached segment automatically forward step by step. A stationary pawl locks the sector in position before the punch enters the material, and the machine stops automatically after the predetermined number of strokes have been made. The die is so shaped that, while cutting the slots, the inner edge of the segment is simultaneously

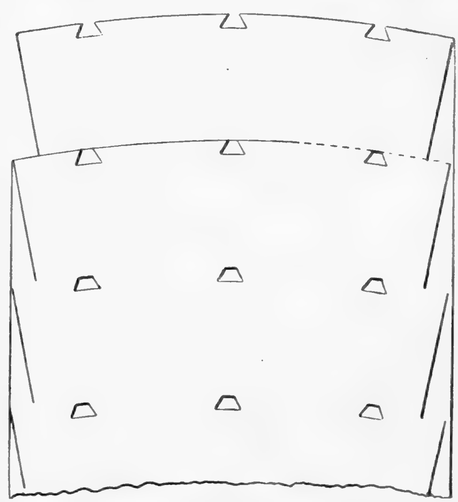


Fig. 47.—Drawing showing result of Shearing Operation.

finished, and the segment is thus brought to the form shown in Fig. 49.

Ordinarily, for handling a given segment in this machine, it is merely required to provide a sector with the right number of notches and of suitable radius, as the slotting punches and dies (which are quite simple in construction) are usually standardised

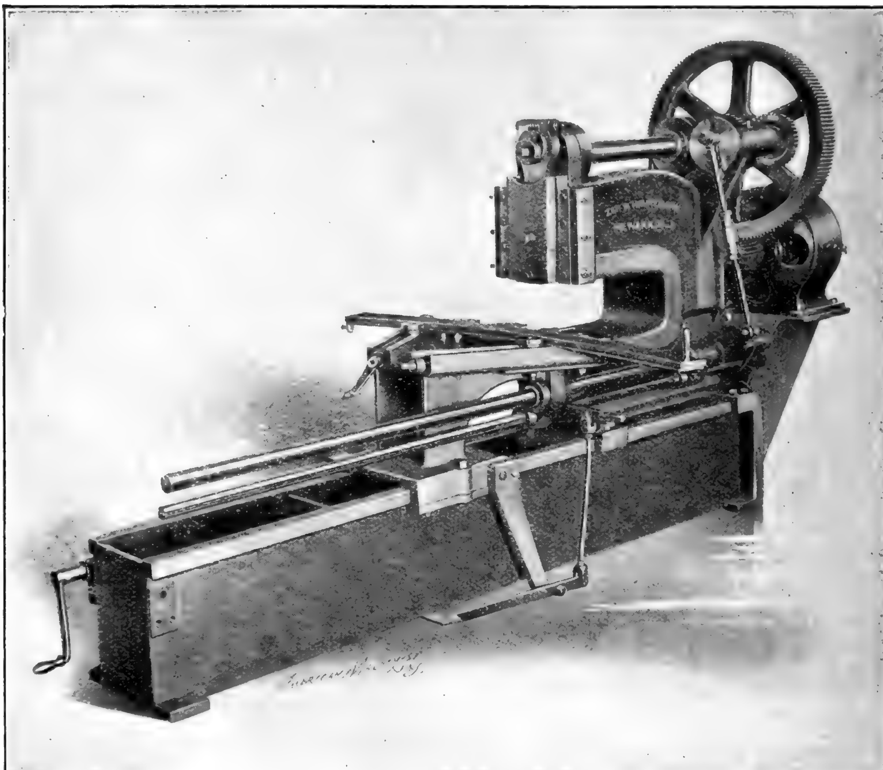


FIG. 48.—Photo of Notching Machine. Zeh & Hahnemann.

as to shape, to allow their use on other segments. Since the masses to be accelerated at each stroke of the press are small, the machine can be run at good speed without endangering the accuracy of the results.

The rotary shear and the slotting machine may be used for cutting and slotting full discs or rings of smaller diameters by substituting suitable attachments. The slotting press will slot segments and rings on the outside as well as on the inside, and, as the throat of the press is 18 inches deep, the internal slotting of segments and rings up to that radial depth is possible.

It is obvious that there is no upper limit as regards diameter, as the machine will take in work of any curvature up to a straight line, and without sacrifice of floor space.

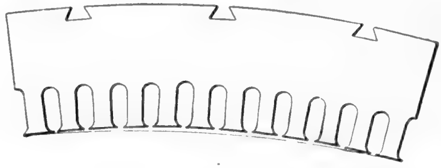


Fig. 49.—Drawing showing Segment Notched and Trimmed.

Allusion has already been made to the great pressures required for compound dies, and, in the example worked out for a compound

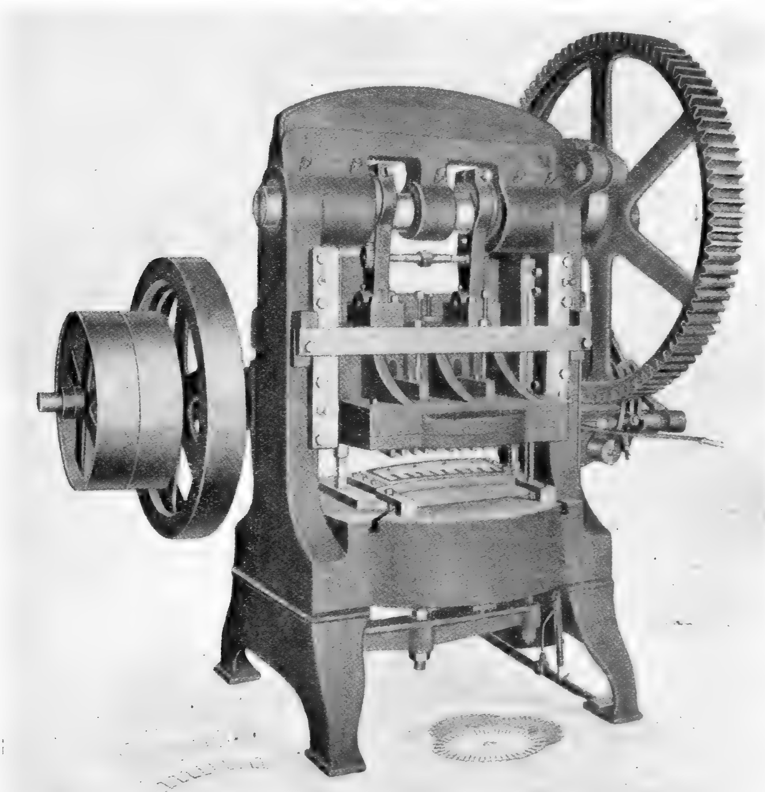


Fig. 50.—Geared Armature Disc-cutting Press.

die for punching discs of the dimensions shown in Fig. 23, this amounted to 240 tons.

Two representative types of presses for such work are shown in Figs. 50 and 51.

It would exceed the limitations of this treatise to deal with any more of the many interesting and ingenious machines and devices which have been placed on the market by various

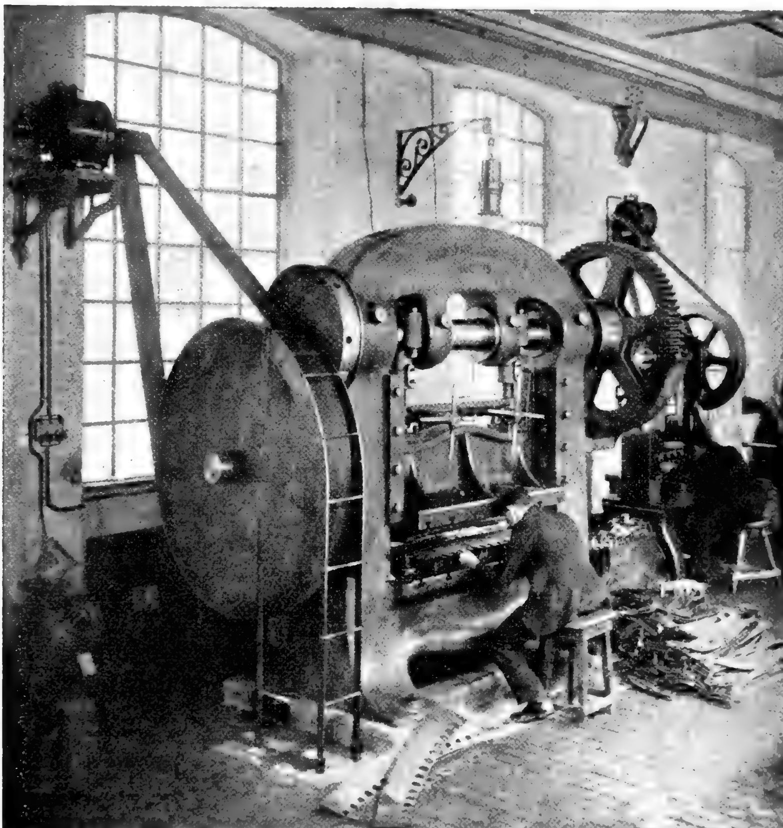


FIG. 51.—Geared Armature Disc-cutting Press.

firms, for use in the manufacture of armature core plates. A manufacturer of dynamo-electric machinery will supplement the information set forth in this treatise by a careful comparative investigation of the machinery of a number of established firms, and for this purpose the following necessarily incomplete list of some makers of armature disc stamping machines may be useful :—

The E. W. Bliss Co., Brooklyn, New York, U.S.A.
Breuer, Schumacher & Co., Kalk, near Cologne.
Brüder Scherb, Vienna, XX Dresdnerstrasse, Nr. 107.
German-Niles-Tool Works, Ober Schöneweide, near Berlin.
Ludwig, Loewe & Co., Hutten Strasse 17–20, Berlin.
Neville Brothers, 7 and 9 James Street, Liverpool.
Niles-Bement-Pond Co., 23 and 25 Victoria Street, London, S.W.
Daniel Smith & Co., Castle Iron Works, Wolverhampton.
Taylor & Challen, Ltd., Constitution Hill, Birmingham.
Robert Tümmler, Döbeln in Sachsen.

CHAPTER III

THE ARMATURE FRAME

A FRAME is required for the mechanical support of the armature core plates. When the armature is the rotor, this support generally consists of an internal hub or spider intermediate between the shaft and the laminations. The laminations are compressed between flanges secured at each end of the spider. These flanges are often extended to form a support for the end connections of the armature winding.

Fig. 52 shows the armature spider of a 10-pole, 300 k.w., 100 r.p.m. generator. In this case there are six spider arms, and two recesses per arm are provided for bolts which pass through holes in lugs projecting inwardly from the armature core plates. Fig. 53 shows one core plate in place on this spider. In Fig. 54, the end flanges are shown in place on the spider, the core plates being omitted. A similar construction is shown in Fig. 55; this is for a 6-pole, 200 k.w., 135 r.p.m. machine. The spider has eleven arms, and receives only one lug per arm. Thus, instead of an integral number of core-plate segments per complete disc (as in Figs. 52 and 53, where there were six complete segments per disc), there are, in the case of Fig. 55, five and a half segments per disc, so that, in assembling the core-plate segments, the last half of the sixth segment laps over into the next layer. In both cases the core plates are secured by bolts passing through rectangular lugs, as seen in Figs. 54 and 55. In the case illustrated in Fig. 56, however, which shows the spider of a 6-pole, 250 k.w., 320 r.p.m. generator, the core-plate segments are retained by dovetailed lugs engaging in corresponding recesses in the ends of the spider arms. In this case, the bolts compressing the core plates between the end flanges are entirely below and separate from the armature core. In Figs. 57 and 58 are given photographs of spiders of

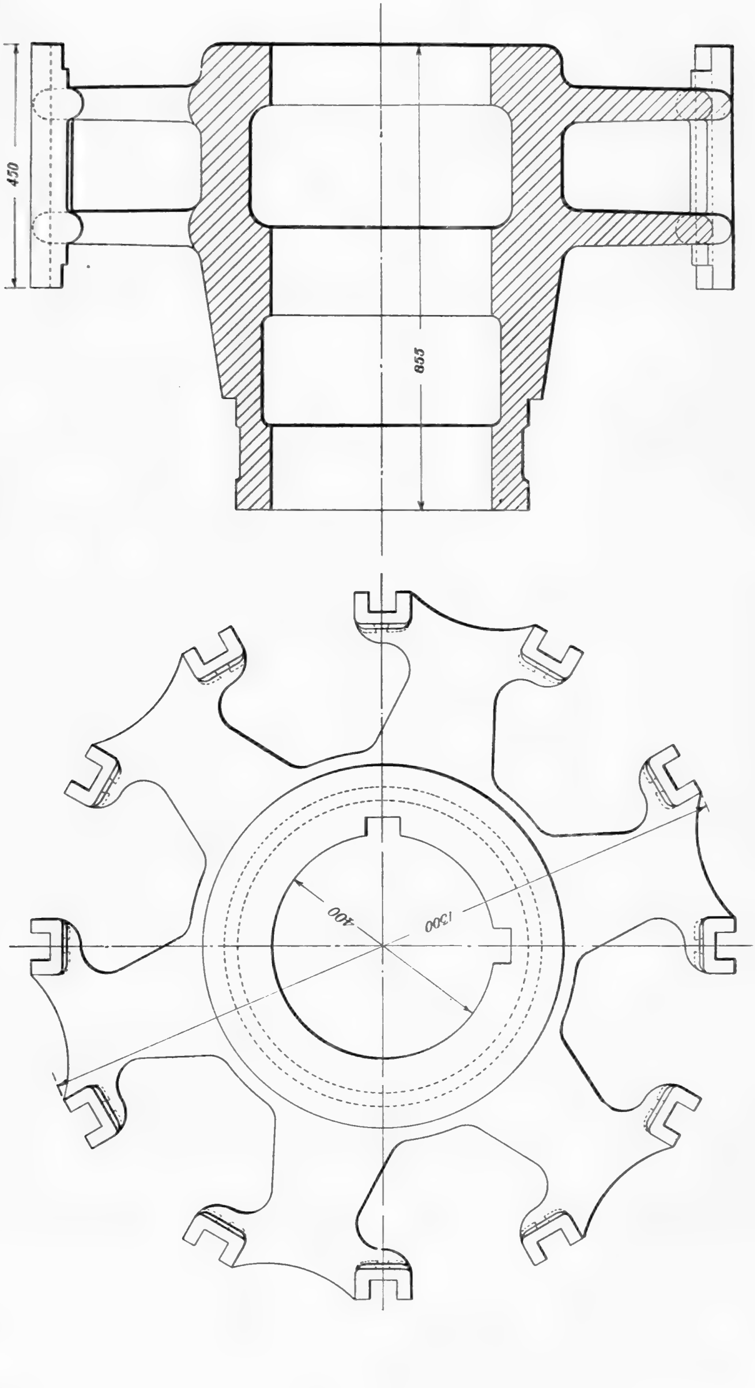


Fig. 52.—Armature Spider of 10-pole, 300 k.w., 100 r.p.m. Generator.

other designs, where the dovetailed construction is employed. In these cases, two and four dovetails respectively are employed

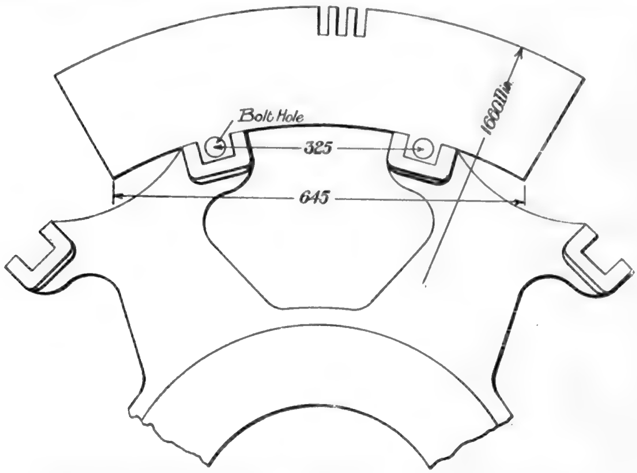


FIG. 53.—Armature Spider of 300 k.w. Generator, showing one Core Plate in place.

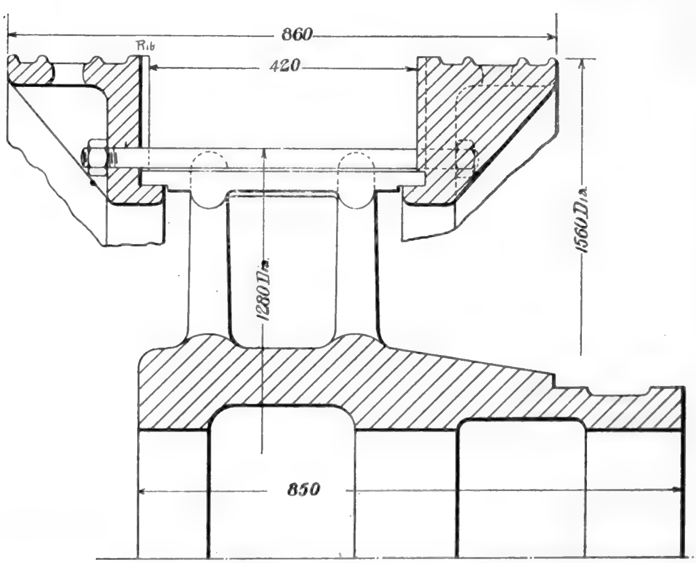


FIG. 54.—Armature Spider of 300 k.w. Generator, showing end Flanges.

for each spider arm. In all the cases as yet given, except Fig. 58, there have been two parallel rows of spider arms. In Fig. 58, however, and in the case of the 16-pole, 1000 k.w., 90 r.p.m.

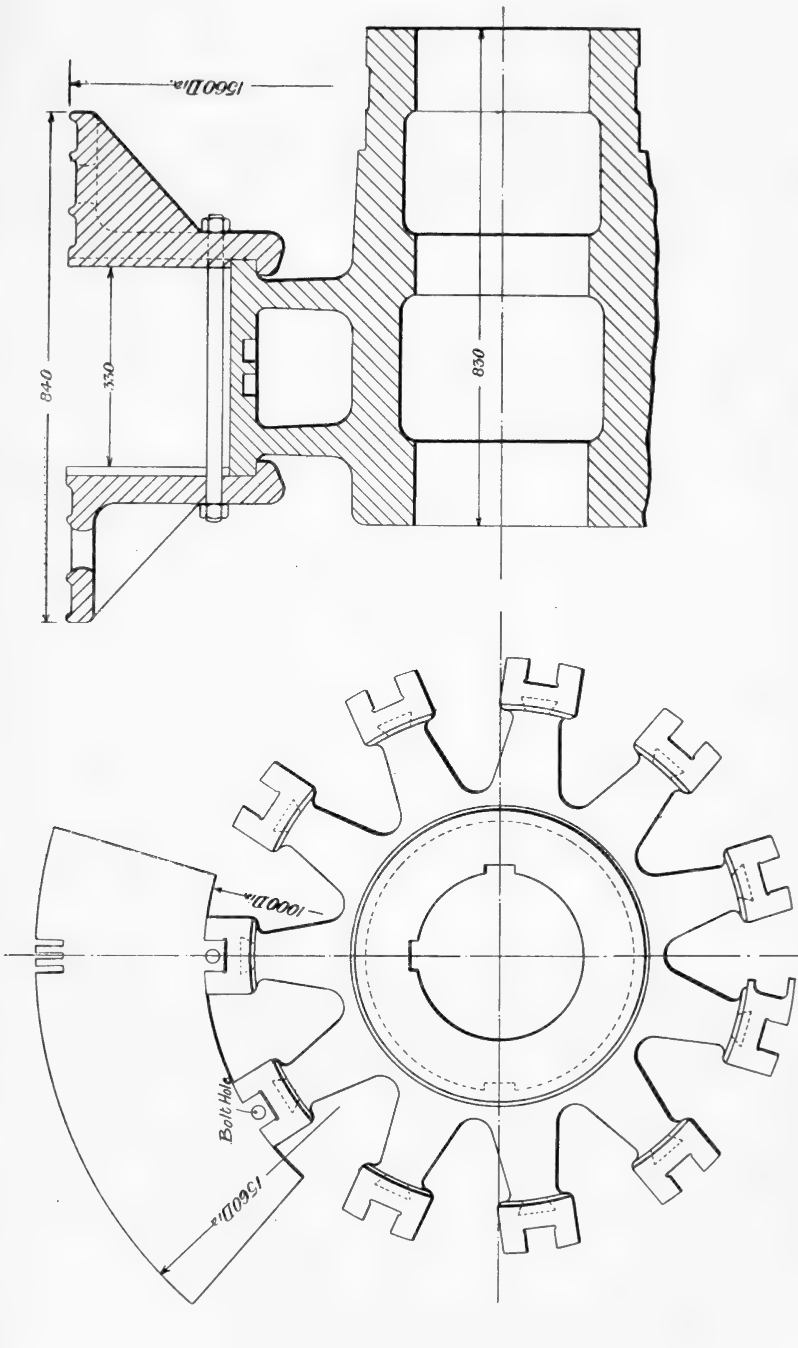


FIG. 55.—Armature Spider of 200 k.w., 6-pole, 135 r.p.m. Generator.

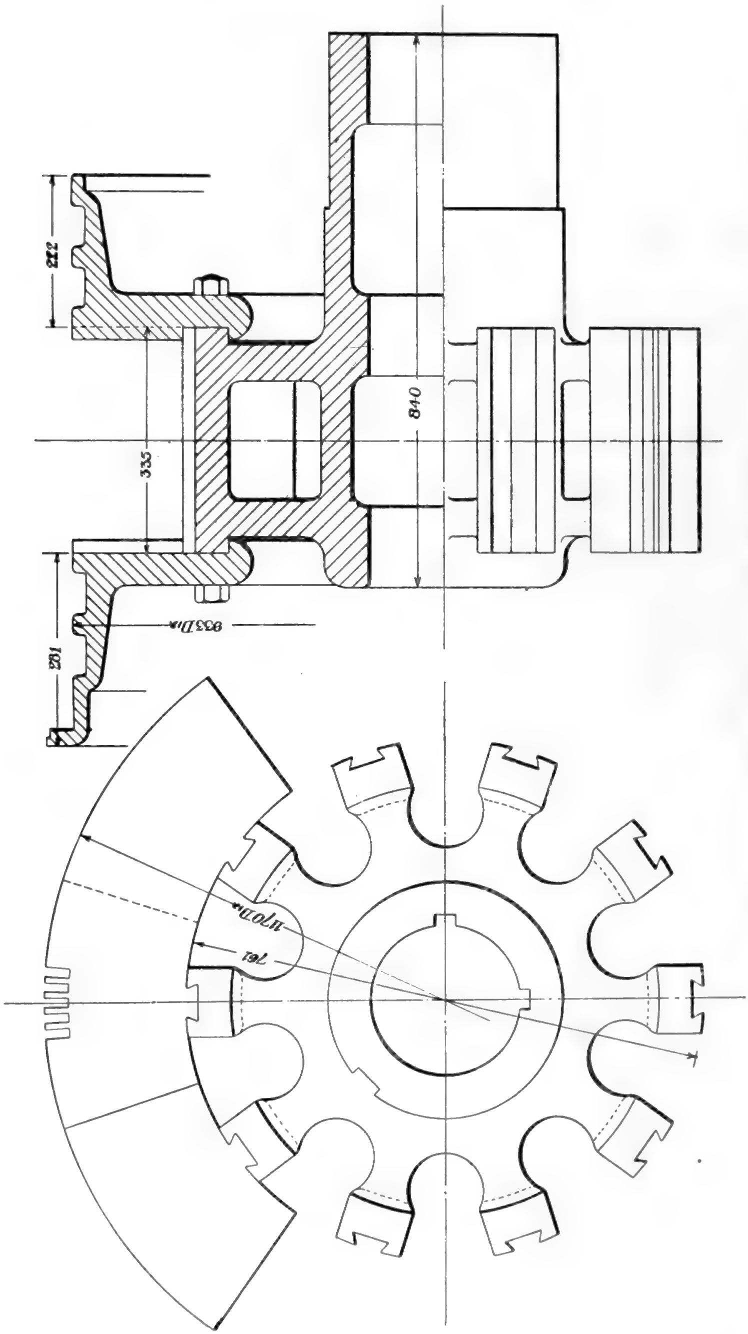


FIG. 56.—Armature Spider of 250 k.w., 6-pole, 320 r.p.m. Generator.

generator, drawings of whose armature spider are given in Fig. 59, only one row of spider arms is employed.

In machines in which, owing to small size or high speed, or both, the internal diameter of the armature laminations is small, the armature spider with arms is replaced by a sleeve carrying the

FIG. 57.—Photograph of Armature Spider of large Generator. Vickers, Sons & Maxim.

armature core plates. An instance of this practice is given in Fig. 60, which shows the sleeve of the armature of a 117 h.p. gearless railway motor. A related practice consists in assembling the armature core plates directly on the shaft, as in the case of the 27 h.p. railway armature illustrated in Figs. 61, 62, and 63. These last two methods afford much more limited facilities for ventilation of the core, and it is usual, as in the last instance—as may be seen from the figure—to punch out apertures in the core discs, thus providing inlets for the air from the outside to the vertical ventilating ducts. Except in the case of the very largest of continuous-current turbo-generators, a similar difficulty is encountered. In the case of the design for a 750 k.w. generator at 1500 r.p.m., the difficulty is met as shown in Fig. 64.

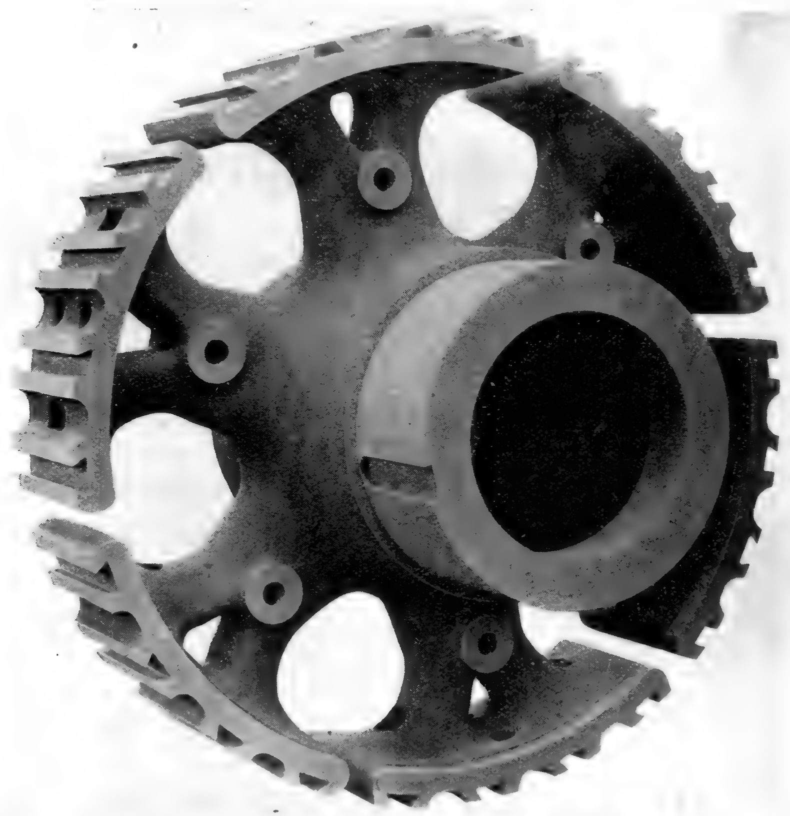


FIG. 58.—Photograph of Armature Spider of large Generator. Dick, Kerr & Co.

Fig. 65 shows a few alternative methods of keying the laminations to the spider arms.

For external stationary armatures, the punchings may be assembled in skeleton castings of a variety of designs, of which a few typical instances are given in Figs. 66 to 73.

Fig. 66 shows the casting for the frame of a moderate size stationary armature. In the front of the frame is seen one of the end flanges cast on to the frame itself. The armature core rests against this flange at one end, and there is a detachable flange at the other end of the armature to clamp the core in place.

Figs. 67 and 68 illustrate front and back views of a 1500 k.w. alternator armature frame. In Fig. 67 will be noted the

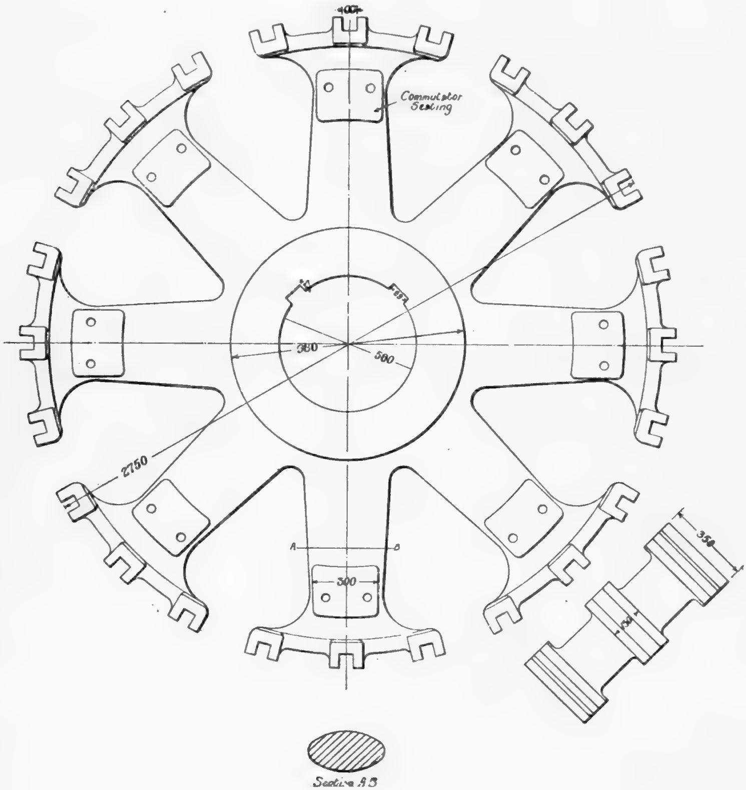


FIG. 59.—Armature Spider of 1000 k.w., 16-pole, 90 r.p.m. Generator.

fixed end flange similar to that in Fig. 66. This frame is split into two equal parts with a horizontal division, as is necessary in very large frames. Fig. 68 shows the skeleton structure of the frame; it consists of an inner and outer shell, the inner pierced by a large number of apertures webbed together by axial and circumferential ribs. A section through a frame of the same type as Figs. 67 and 68 is shown in Fig. 69. In this case both the inner and outer shells are perforated with

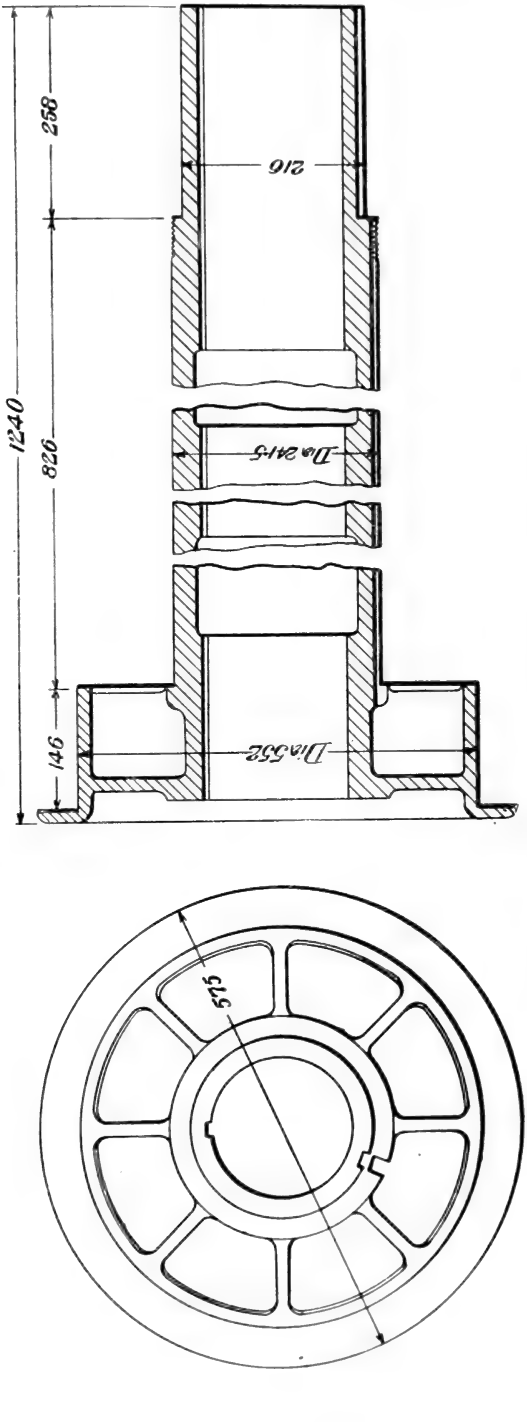


Fig. 60.—Armature Sleeve of 117 h.p. Gearless Railway Motor.

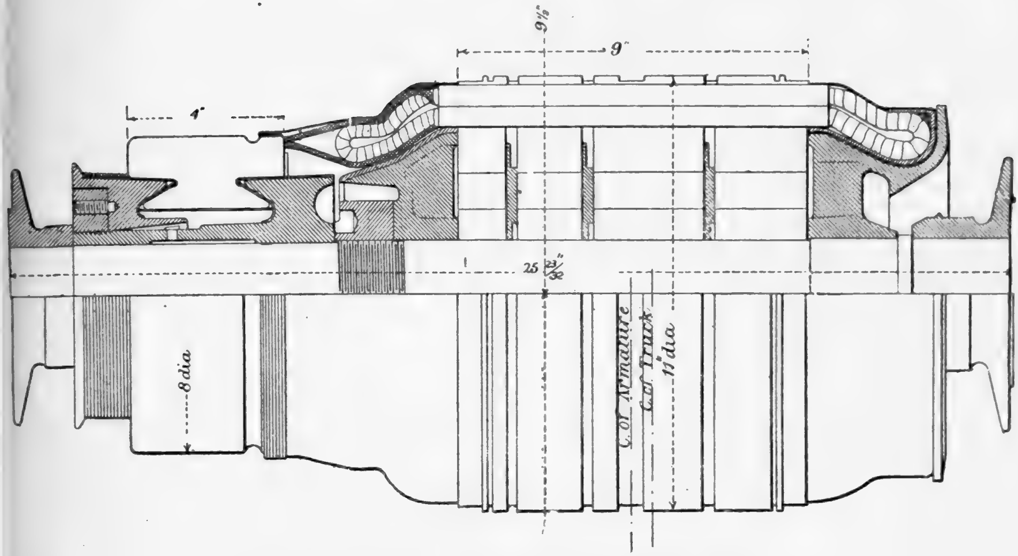


FIG. 61.—Armature Assembly of 27 h.p. Railway Motor.

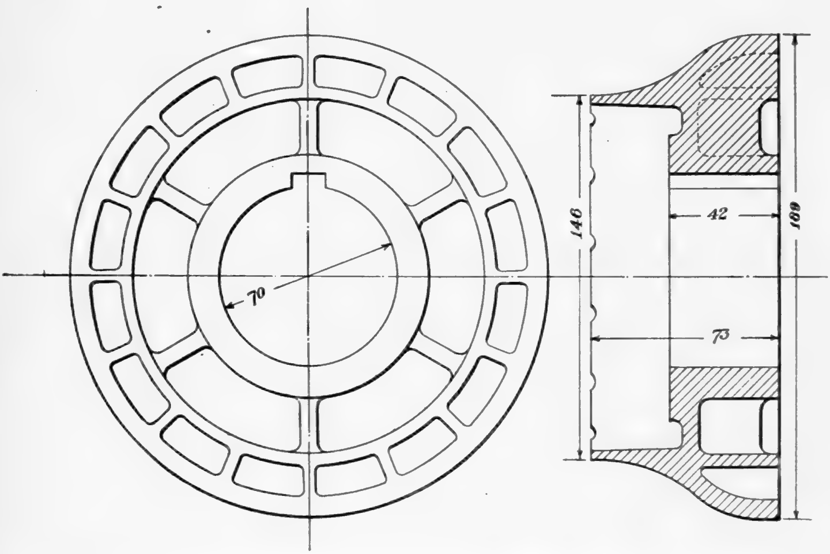


FIG. 62.—Armature End Bracket for 27 h.p. Railway Motor (Commutator End).

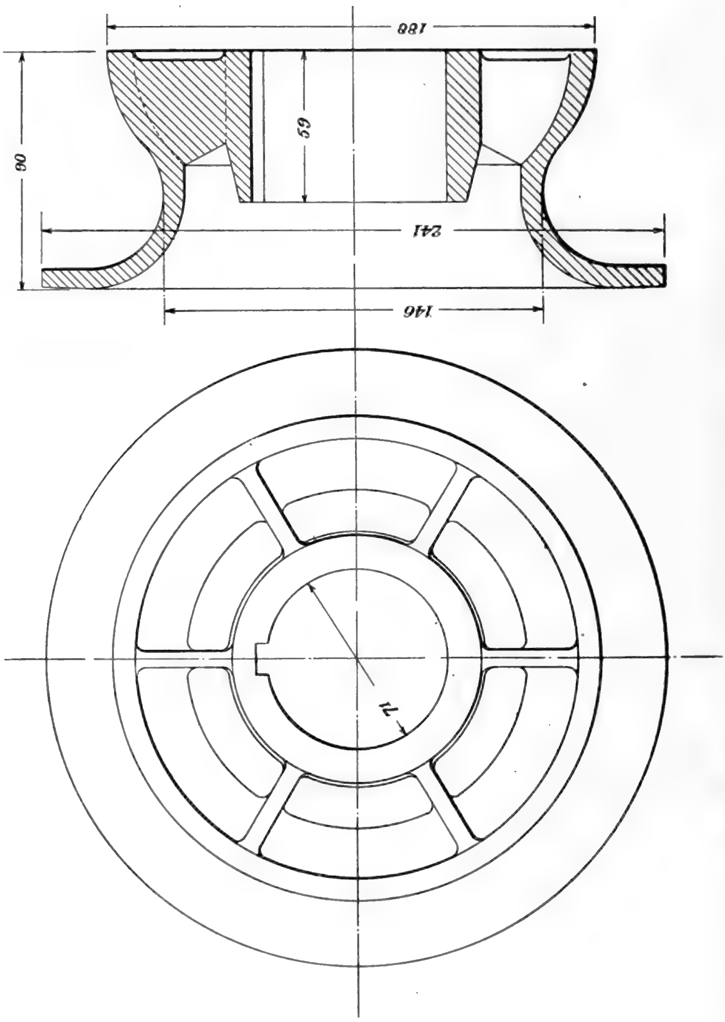


FIG. 63.—Armature End Bracket for 27 h.p. Railway Motor (Back End).

large holes. This assists the ventilation and also effects a saving in weight.

In Fig. 69 the armature laminations are not held together to the frame by bolts connecting the two end plates, but they are secured by a number of short keys (K) driven in circumferentially between the loose end flange and a circular rib on the frame. This construction has obtained considerable use recently, and it

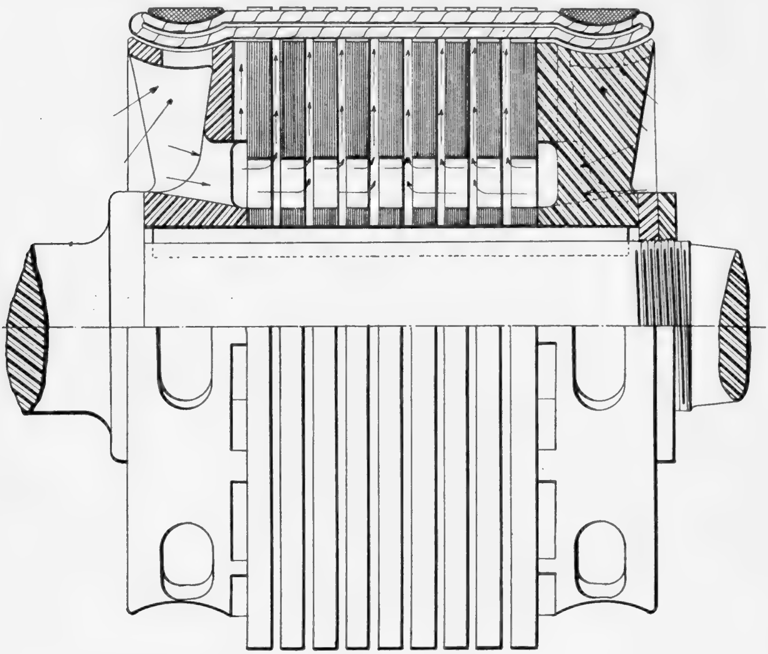


Fig. 64.—Armature of 750 k.w. 1500 r.p.m. Generator, showing Ventilating Arrangements.

dispenses with bolts passing through the stampings or connecting the end flanges.

Fig. 70 shows a section through a large frame of the box type, which is common practice for very large frames. Here the core is clamped up between two end flanges neither of which is a part of the frame, the bolts being just outside the circumference of the laminations. The laminations are secured to the frame by dovetail keys. In some cases the frame is made in two exactly similar halves, bolted together by bolts usually inside the box part of the frame, as shown in Fig. 71. In this frame the armature laminations are assembled in one half of the frame, and the other half laid on and the two bolted together.

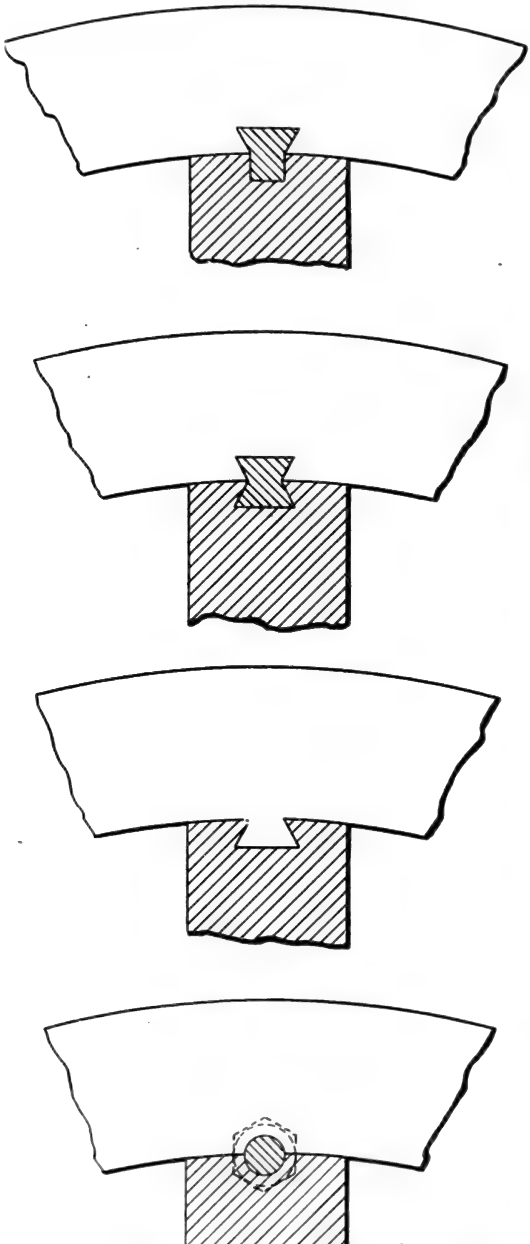


FIG. 65.—Methods of Keying Armature Laminations.

In stationary armatures of large diameter it is necessary for the section of the frame to be of considerable depth, to render it sufficiently rigid to stand its own weight and that of the armature, without deflecting.[1] In cases of very large frames (up to 30 feet diameter) they are sometimes stiffened up by a system of tie-rods arranged round the outside of the frame. The results obtained by this latter method have not been altogether satisfactory.

Fig. 72 shows a typical frame for smaller size armatures.

[1] A useful method of determining the dimensions of box type frames is given by R. Livingstone in the *Electrician*, vol. lvii. pp. 569–571, 1906: "Some Notes on the Mechanical Design of Electrical Generators."

Fig. 73 is a similar frame, but made in two exactly similar halves drawn together by bolts.

Fig. 74 shows a light grid construction of frame suitable for induction motors and small alternators. It leaves the exterior of the laminated core well exposed to the air, and is thus excellent from the standpoint of the thermal design. The end flanges are retained by circumferential keys, as shown.

Fig. 66.—Casting for Frame of Stationary Armature. Scott & Mountain.

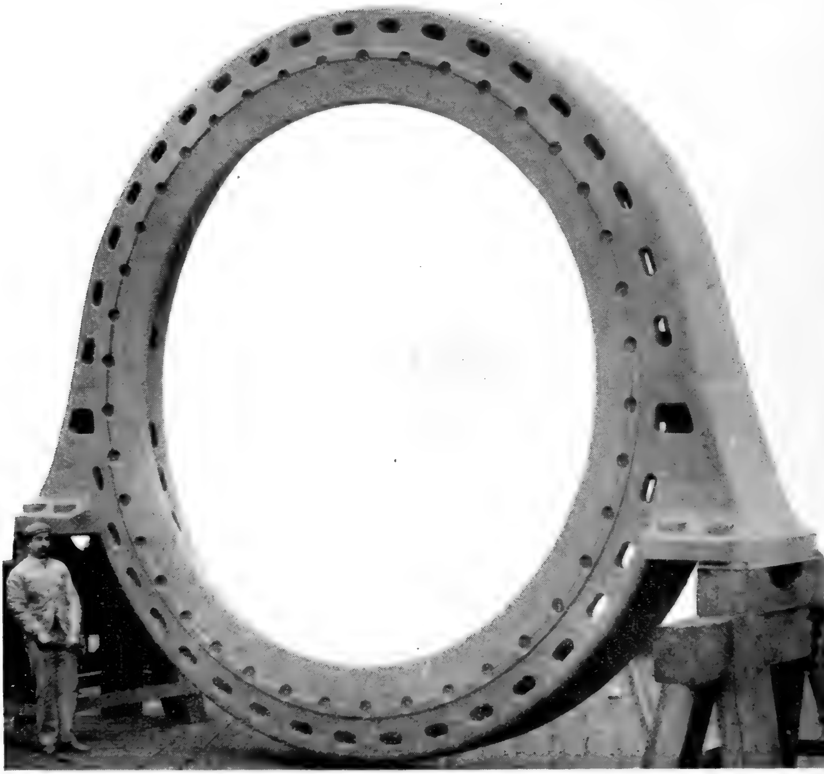


FIG. 67.—Casting for Frame of Stationary Armature. Dick, Kerr & Co.

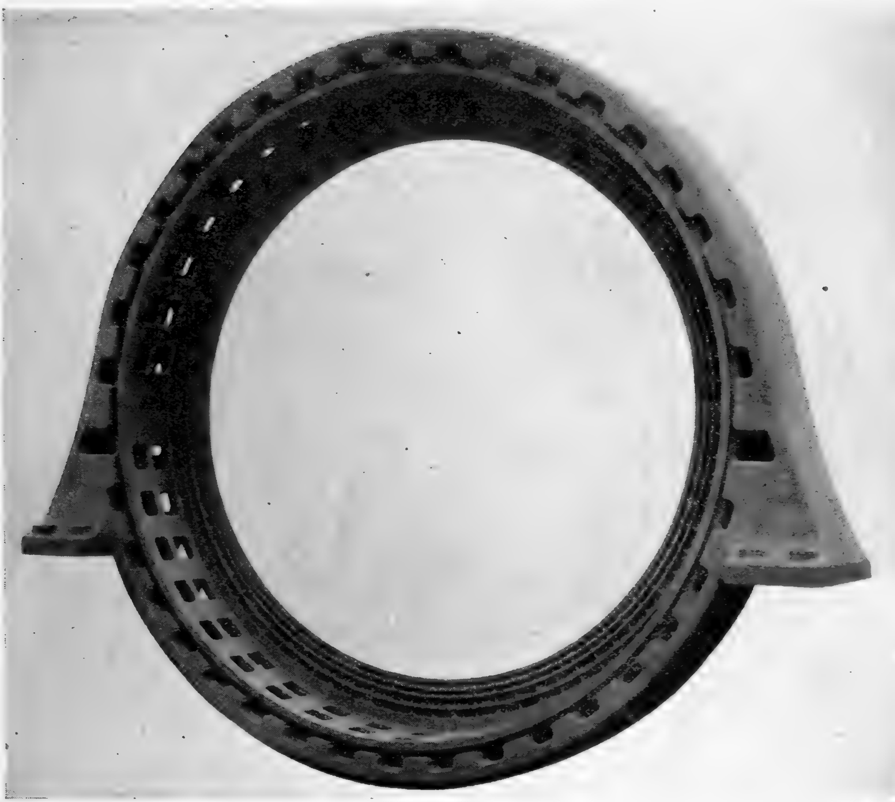


Fig. 68.—Casting for Frame of Stationary Armature. Dick, Kerr & Co.

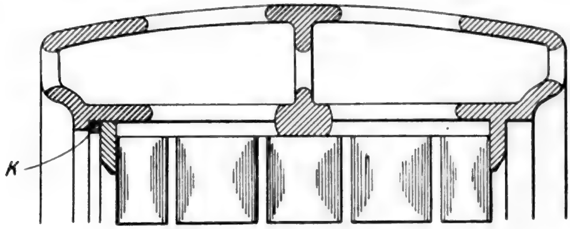


FIG. 69.—Box Type Frame for Stationary Armature of medium size Alternator.

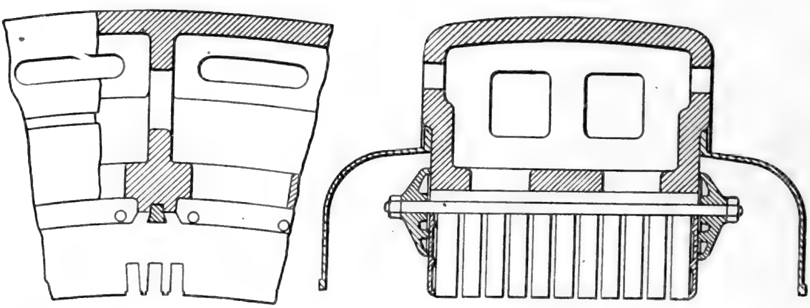


FIG. 70.—Box Type Frame for Stationary Armature of large Alternator.

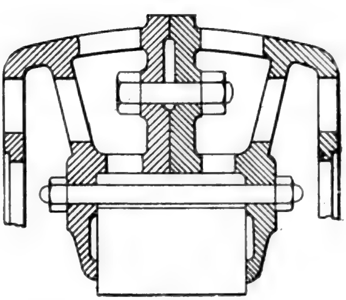


FIG. 71.—Split Frame for Stationary Armature of large Alternator.

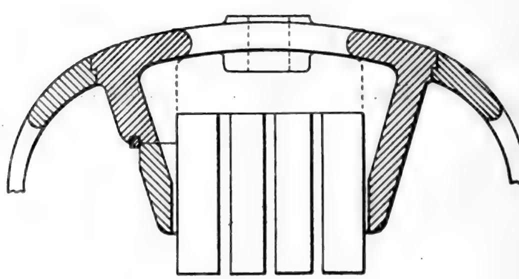


FIG. 72.—Frame for Stationary Armature of small Alternator.

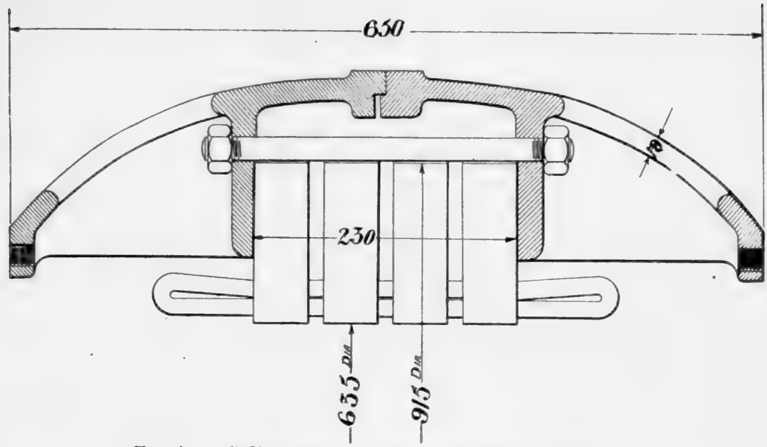


FIG. 73.—Split Frame for small Stationary Armature.

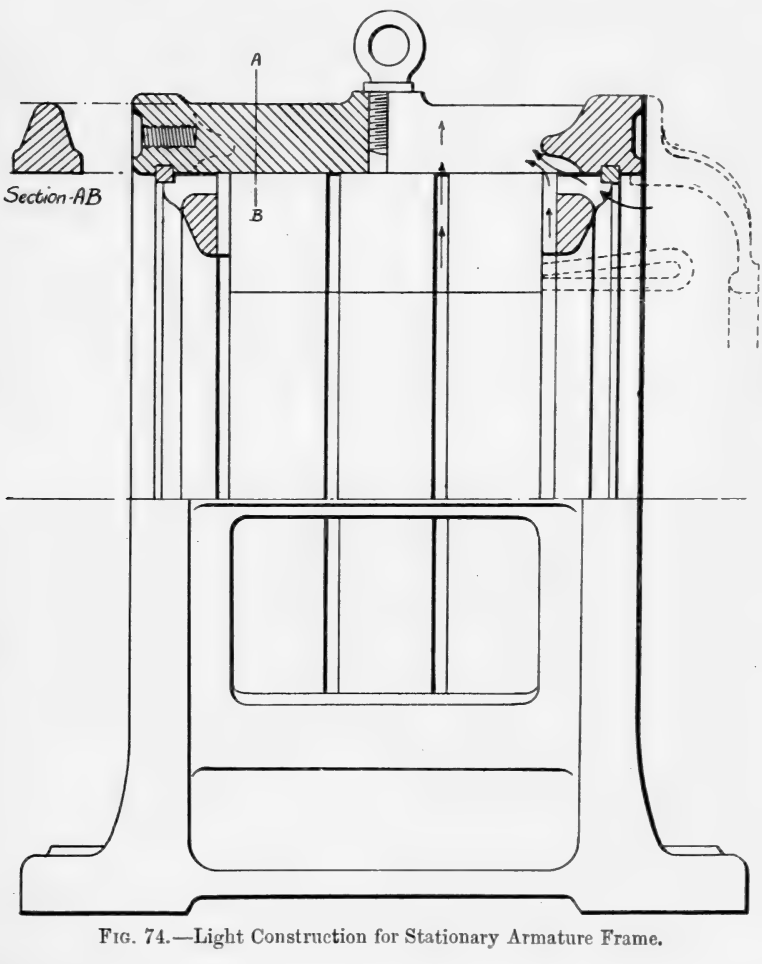


FIG. 74.—Light Construction for Stationary Armature Frame.

CHAPTER IV

ARMATURE CORE VENTILATING PIECES

WHILE amongst the work of the earliest dynamo builders we find frequent instances of careful attention to the provision of means for ventilation, it may nevertheless be said that this aspect of dynamo design has been greatly neglected. In the present treatise we are concerned only with the ventilation of the armature, and, in this particular chapter, with the means for providing radial

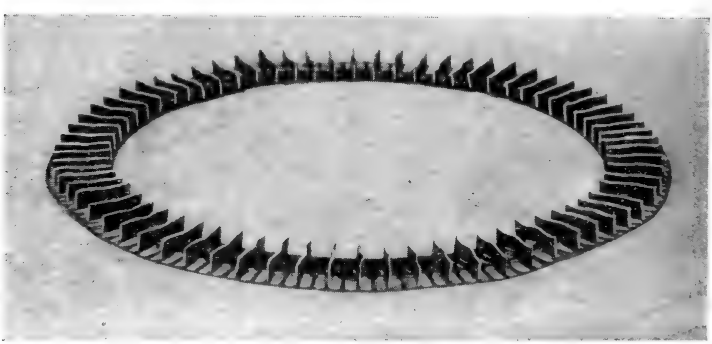


FIG. 75.—Ventilating Distance-piece. Allmanna Svenska Elektriska Aktiebolaget.

ducts through the armature core. At the time when slot-wound armatures first came into extensive use, the most progressive manufacturers adopted the plan of providing a number of these core ducts, and practice in these companies quickly settled down into following the rule that there should be one duct for every four or five inches of core length. These ducts were often only 6 or 7 mm. wide, and were generally so obstructed by the distance-pieces as to be very inefficient. Some dozen years of experience has made a slight impression on all but the most obdurately retrogressive manufacturers, and a good many manufacturers have already arrived at the stage of employing many more ducts, each duct having a width of some 10 to 15 mm. according to circumstances. The result is that, although of the gross core length, only some 70 per cent., and often a lower percentage, is "effective" iron, the improved ventilation thereby obtained permits of a considerable decrease in the weight of a machine for a given rating. Careful attention is also very often given to the design and construction of the so-called "ventilating pieces," *i.e.* pieces of as skeleton a construction as is consistent with the necessary mechanical strength, and serving the purpose of preserving the required distance between the neighbouring sections of the core.

An interesting example is a ventilating piece employed by the Allmanna Svenska Elektriska Aktiebolaget. This is shown in Fig. 75. It will be observed that this is employed in a design

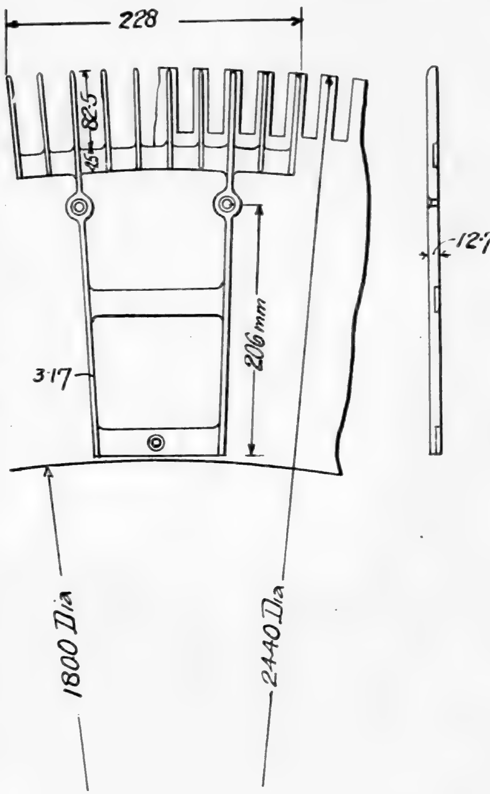


Fig. 76.—Cast Ventilating Distance-piece.

in which the teeth are exceedingly thin; and in order that the "separating-fingers" shall not obstruct the space between the armature coils, there is only provided one finger for every alternate tooth. The authors have seen many an armature in which points of this sort have been utterly neglected, with the result that the "ventilating ducts" are just so much lost space. In some cases, only one "finger" for every third or even fourth tooth could preferably be employed.

A practice to which recourse is often permissible, consists in employing two or three extra thick laminations on each side of the duct, to prevent the teeth from spreading towards the duct, and to decrease the liability of breaking off at the roots, in which case comparatively few fingers need be employed. These fingers may in such cases project but part way to the surface, or every other finger may project to the surface, the alternate fingers stopping off at—or, preferably, quite a little below—the bottom of the slots. Cast distance-pieces, in spite of their cheapness, are gradually being abandoned, as they

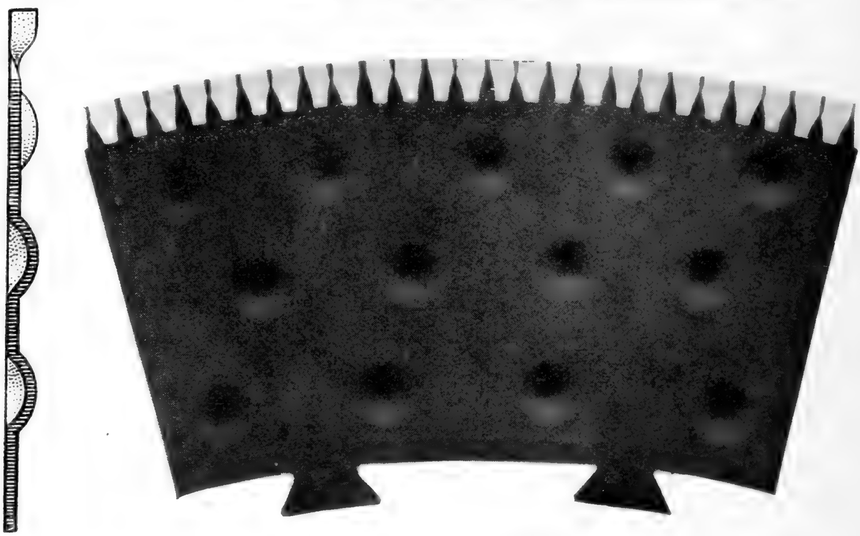


FIG. 77.—Ventilating Spacing-piece. Dick, Kerr & Co.

occupy too much of the space which ought to be left free. In Fig. 76, however, we have given a typical cast spacing-piece which has been employed on a 550 k.w. 10-pole traction generator, of which a number are in use in Great Britain.

The ventilation of armatures with a comparatively small number of teeth per pole may more readily be made effective, since each tooth will be comparatively quite wide at the root, and hence the openings between the coils will be more free for the discharge of air. Other instances of good designs of ventilating pieces are shown in Figs. 77 to 83. Fig. 77 shows a method which has been used by Messrs Dick, Kerr & Co., where the stampings are spaced at the teeth by twisting the teeth of one of the laminations at right angles.

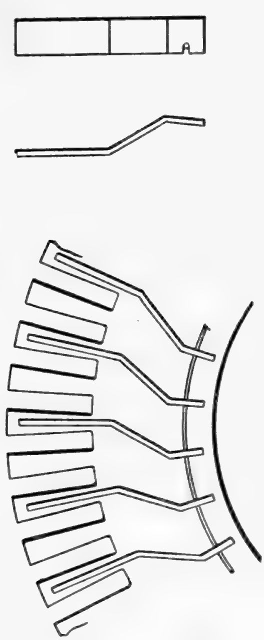


Fig. 78.—Ventilating Spacing-piece.

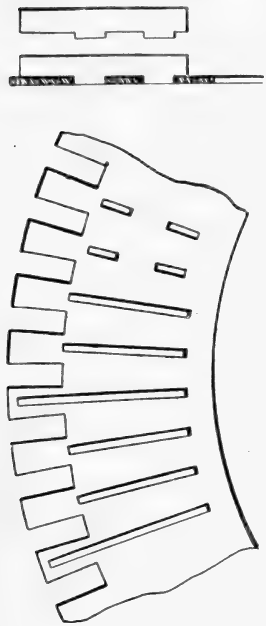


Fig. 79.—Ventilating Spacing-piece.

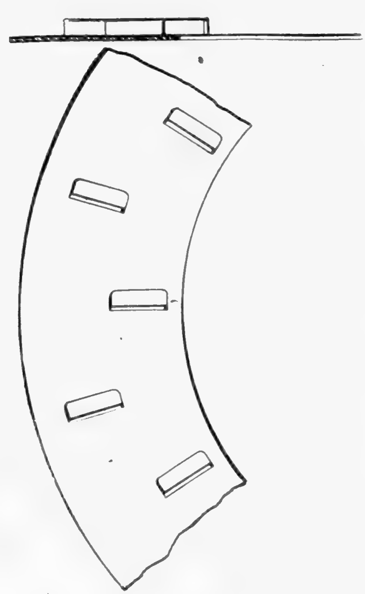


Fig. 81.—Ventilating Spacing-piece. British Thomson Houston.

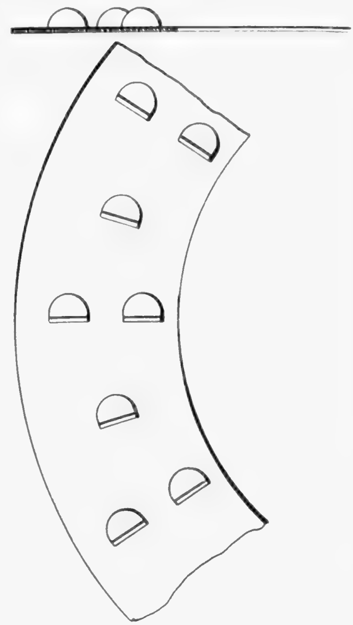


Fig. 82.—Ventilating Spacing-piece. British Westinghouse.

The lower parts of the laminations are spaced by hemispherical projections pressed out from the lamination itself to a height equal to the width of the duct. It may be noted that this construction simply utilises a single core plate on one side of the duct, without introducing any extra pieces.

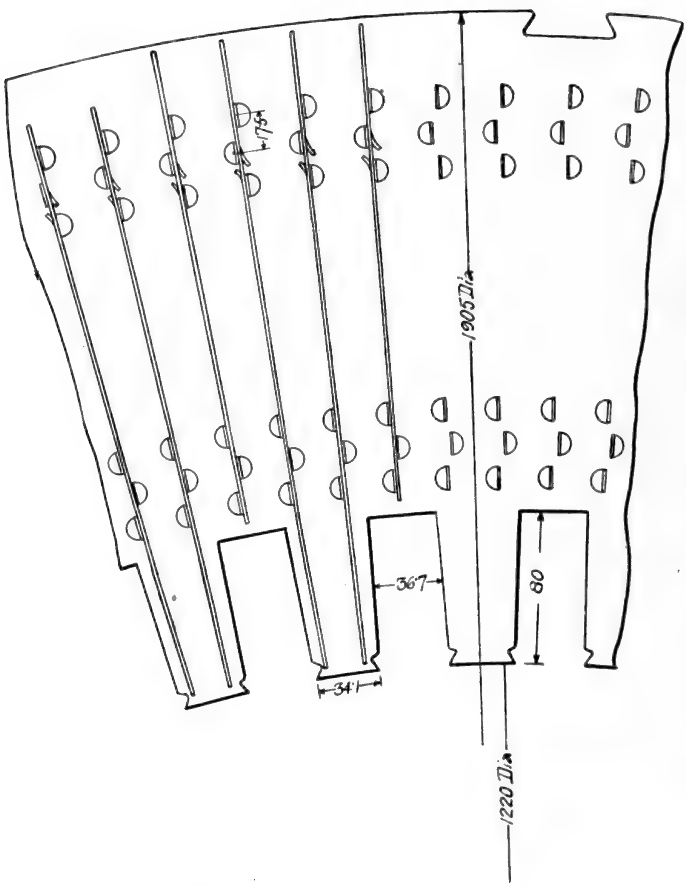


FIG. 80.—Ventilating Spacing-piece. British Thomson Houston.

As stated above, cast spacing-pieces are being abandoned and replaced by sheet metal fingers on edge, the variations in the different designs relating principally to the method of securing the sheet metal fingers.

A method is shown in Fig. 78 in which the fingers are shrouded together with a ring of wire, riveted into a notch in the side of each finger. These fingers may be curved or shaped in any convenient way so that they will stand up firmly on the core plate and offer least resistance to the ventilating air.

In Fig. 79 the fingers are fixed to one core plate by means of projections fitting into small slits punched in the plate. The fingers are fitted into these slits one at a time, and riveted over by

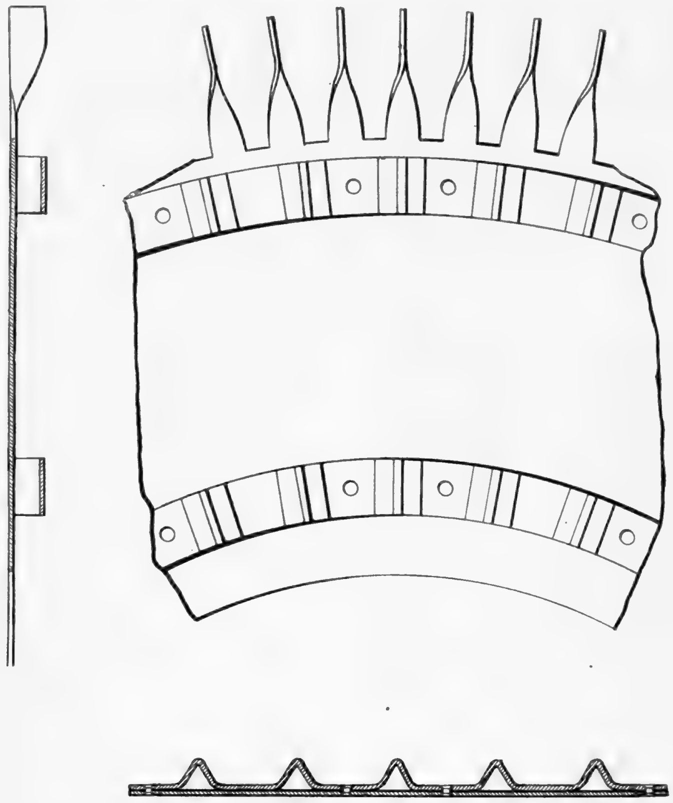


FIG. 83.—Ventilating Spacing-piece. Vickers, Sons & Maxim.

hand at the back of the plate, rendering them quite firm. This is a very efficient construction, but the process of riveting the fingers into the laminations by hand is rather laborious.

Fig. 80 shows a satisfactory construction which is employed in the B.T.H. 1500 k.w. 1000 r.p.m. turbo-alternators, supplied to the Yorkshire Electrical Power Company.

Figs. 81 and 82 show further methods of the British Thomson Houston Co. and British Westinghouse Co., in which a single plate is used for the space block. As will be seen in both cases, small pieces of the lamination are nicked out in the plate and turned up at right angles.

Fig. 83 is an interesting method used by Messrs Vickers, Sons & Maxim, which may be also seen by a close examination of Fig. 85, Chap. V.

The lower the speed, the smaller the diameter, and the greater the length, the more important does it become to give careful attention to the details of the design of the ventilating scheme and the construction of the spacing pieces.

Where spacing fingers of the types shown in Figs. 78, 79, and 80 are employed, it is a good plan to standardise the width of ventilating duct to be used on all machines, or else adopt one uniform width for small machines and another for large machines. This permits of the spacing fingers being manufactured and stocked in large quantities. The width of duct employed should not be less than 10 mm., nor exceed 20 mm.

CHAPTER V

ASSEMBLING THE ARMATURE CORE

We now have at hand and ready to be assembled, the armature frame, the core laminations, and the ventilating duct distance-pieces.

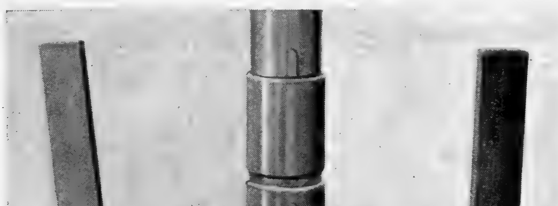


FIG. 84.—Assembling a Standard 15 h.p. Core. Vickers, Sons & Maxim.

Taking first a case where the armature is the rotor, the frame (or spider) is placed on end as illustrated in Figs. 84, 85, and 86. In the case of the small armature shown in Fig. 84, the shaft is already in place, and the laminations, which, in this case, are complete discs, are packed upon it one by one. With the larger armatures illustrated in Figs. 85 and 86, the laminations

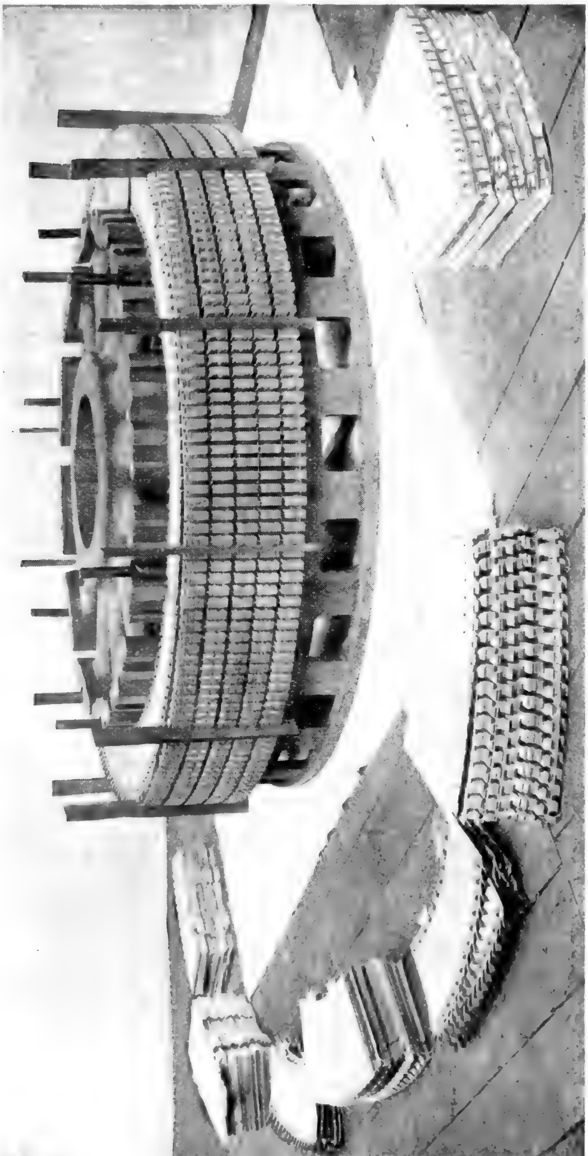


Fig. 85.—Assembling a 750 k.w. Core. (Note the air space separators.) Vickers, Sons & Maxim.

are in the form of sectors, and a number of such sectors are necessary to form a complete disc. These sectors are not dimen-

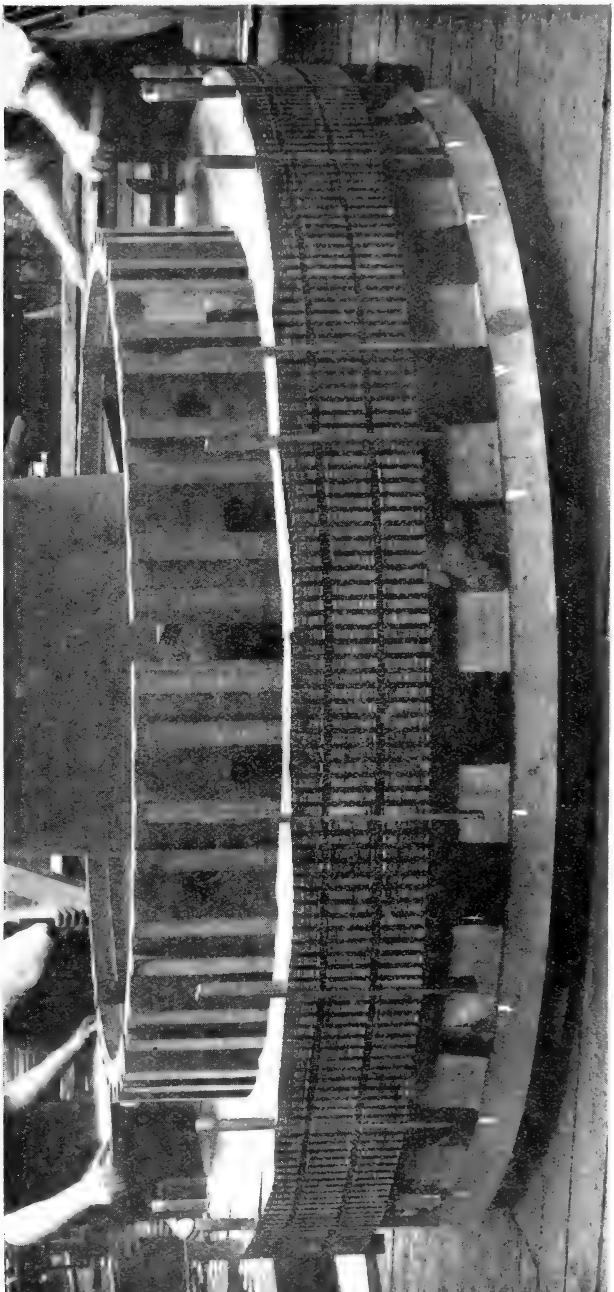


FIG. 86 —Assembling an 1100 k.w. Armature Core. Dick, Kerr & Co.

sioned to abut precisely against one another; on the contrary, a distance of some 0·5 mm. is allowed between the radial sides of neighbouring sectors, as indicated in Figs. 87 and 88.

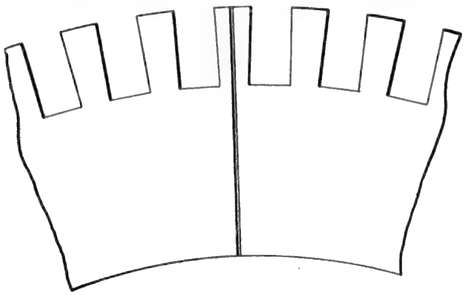


Fig. 87.

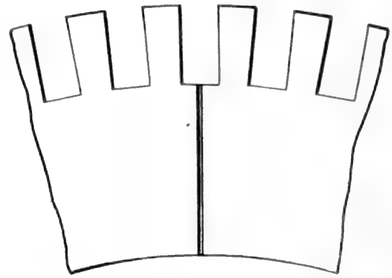


Fig. 88.

Diagrams showing clearance between adjacent Sectors.

It is distinctly preferable to have the division between two sectors along the middle of a tooth (Fig. 87) instead of at the

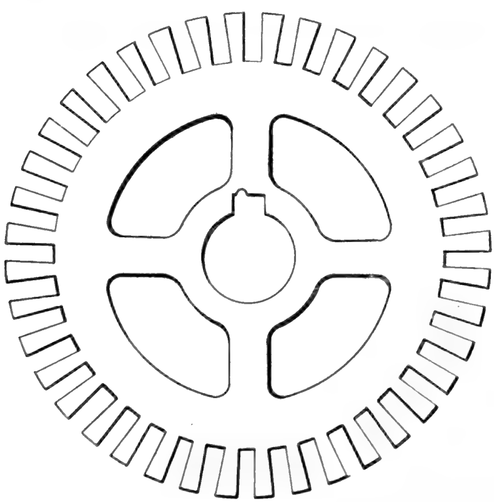


Fig. 89.

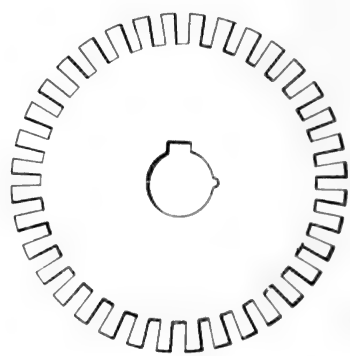


Fig. 90.

Armature Laminations.

middle of a slot (Fig. 88). The two arrangements are indicated in Figs. 87 and 88, and it will be understood from these figures that the disadvantage of the arrangement shown in Fig. 88 is that there is a liability to rough places at the middle of the bottom of the slot, and these will be points of weakness from the insulating standpoint.

Returning to a consideration of Figs. 84, 85, and 86, it will be seen that temporary drifts are set upright in the slots to aid in maintaining a true alignment. This is a point of great importance, and it is the authors' opinion that a larger number of these

FIG. 91.—Assembling the Core of a Stationary Armature. Mavor & Coulson.

temporary drifts could be employed to advantage. Thus in the small armature of Fig. 84 the use of three or four drifts might be desirable. This is because, although the drifts militate slightly against rapid work in assembling the core, they ensure so much more correct alignment as to greatly diminish the amount of filing subsequently required at the sides of the slots, and they may even make it practicable to altogether dispense with the operation of filing the sides of the slots of the assembled core.

The drifts should be of steel, ground very smooth, and tapered at the upper ends. The edges should be rounded off so as to permit of their being driven into place without marring the sides of the slots. If only two drifts are used during assembling, as indicated in Fig. 84, a third and fourth should be driven in

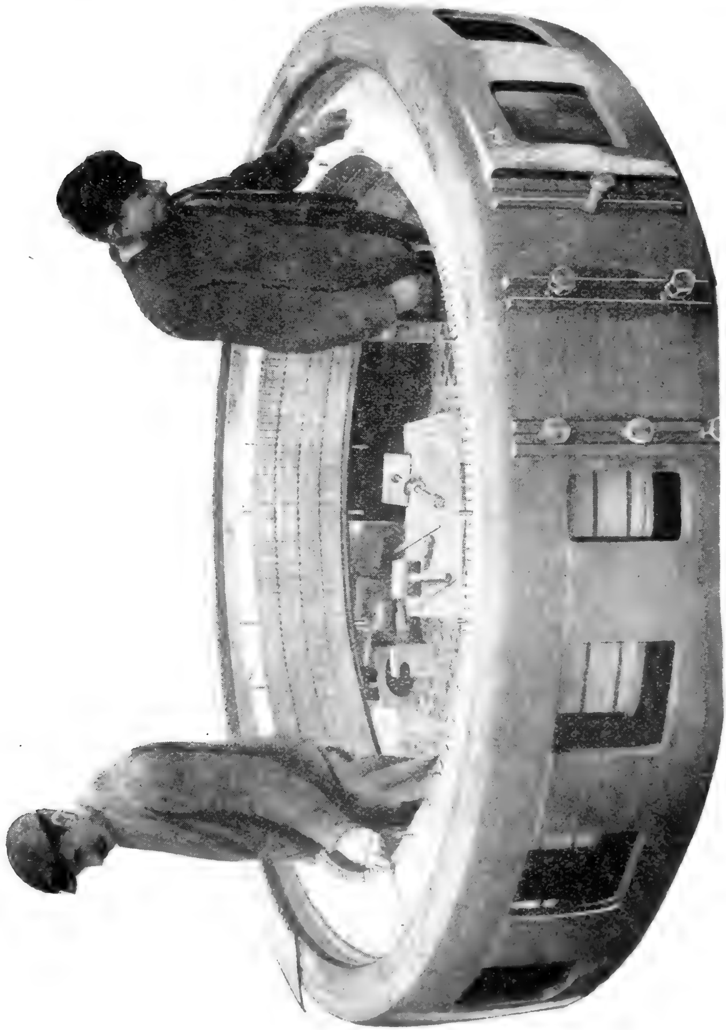


FIG. 92.—Assembling the Core of a large Revolving Field Type Generator. Bruce Peebles.

before the assembled discs are finally pressed up and secured in their ultimate position on the spider. The drifts should not be of more than 0·3 mm. less width than the punch with which the slots were stamped out. The drifts should be considerably longer than the finished core, and while building up the core, they should be slightly inclined outward, as illustrated in Fig. 84, as otherwise, time would be needlessly lost in working the discs down into

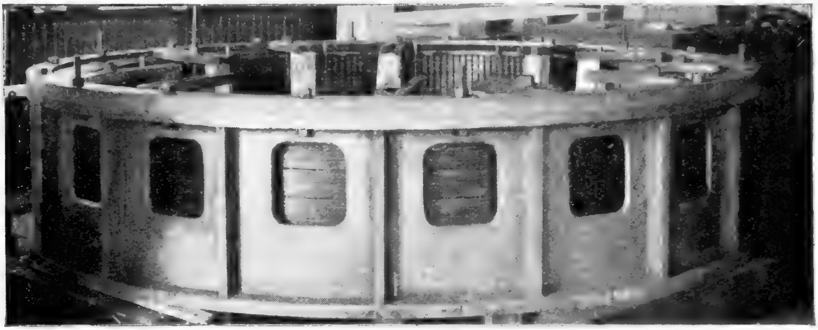


FIG. 93.—Core ready Assembled and under Pressure. Adolf Ungers Industria Aktiebolaget.

place. As the core approaches completion, the drifts should be gradually, by light tapping, forced into a more nearly vertical

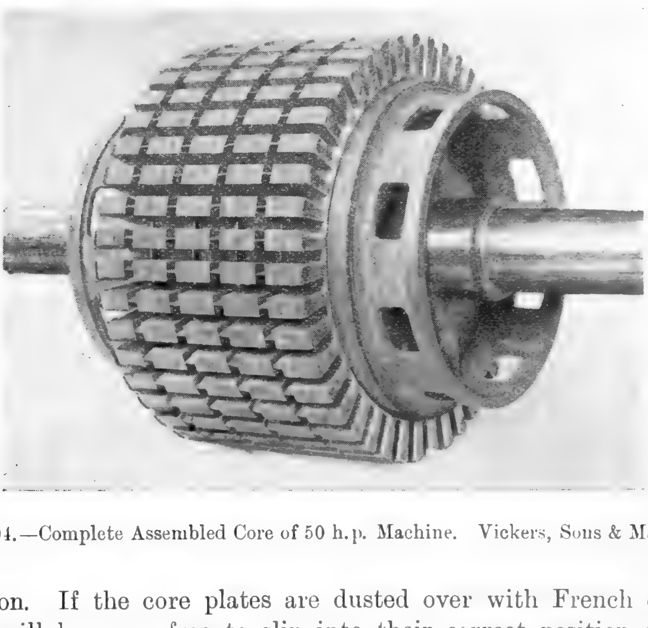


FIG. 94.—Complete Assembled Core of 50 h.p. Machine. Vickers, Sons & Maxim

position. If the core plates are dusted over with French chalk they will be more free to slip into their correct position above one another, and the process of assembling will thereby be facilitated.

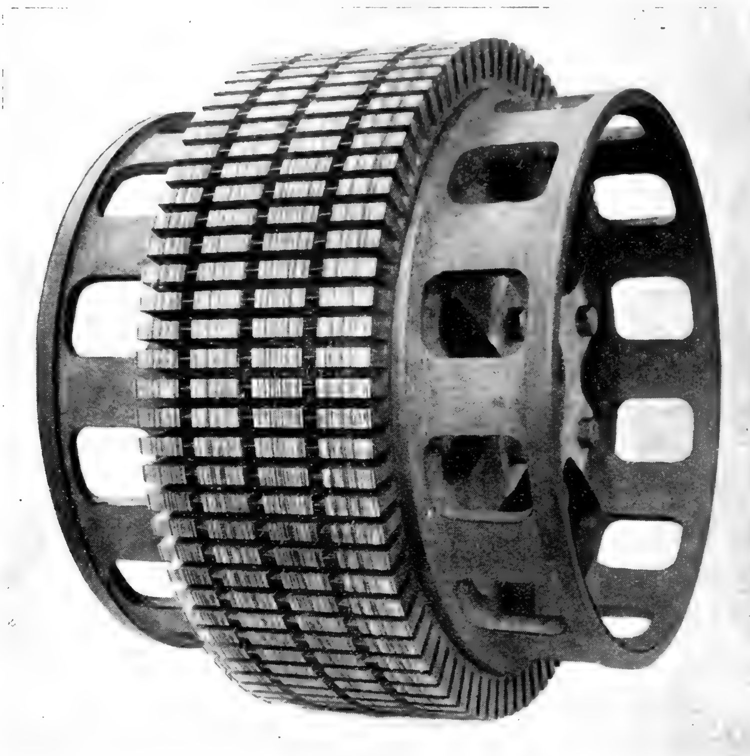


FIG. 95.—Complete Assembled Core of 120 h.p. Motor. Vickers, Sons & Maxim.

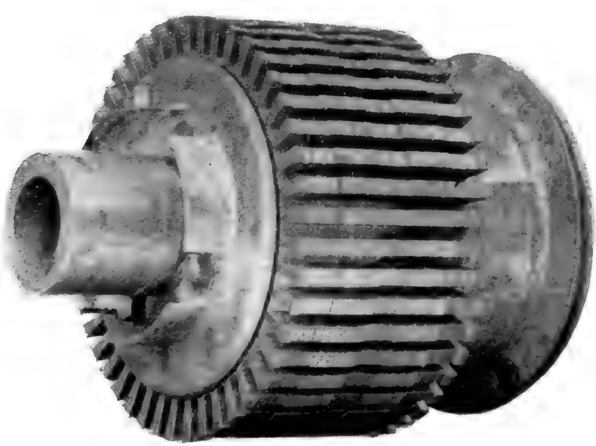


FIG. 96.—Complete Assembled Core of Machine by Alioth Co.

When assembling the punchings, care should be taken that they are all laid with their burred side in the same direction, *i.e.* either uppermost or *vice versâ*. The reason for this is, obviously, to correct for any imperfections in the punches and dies; for if

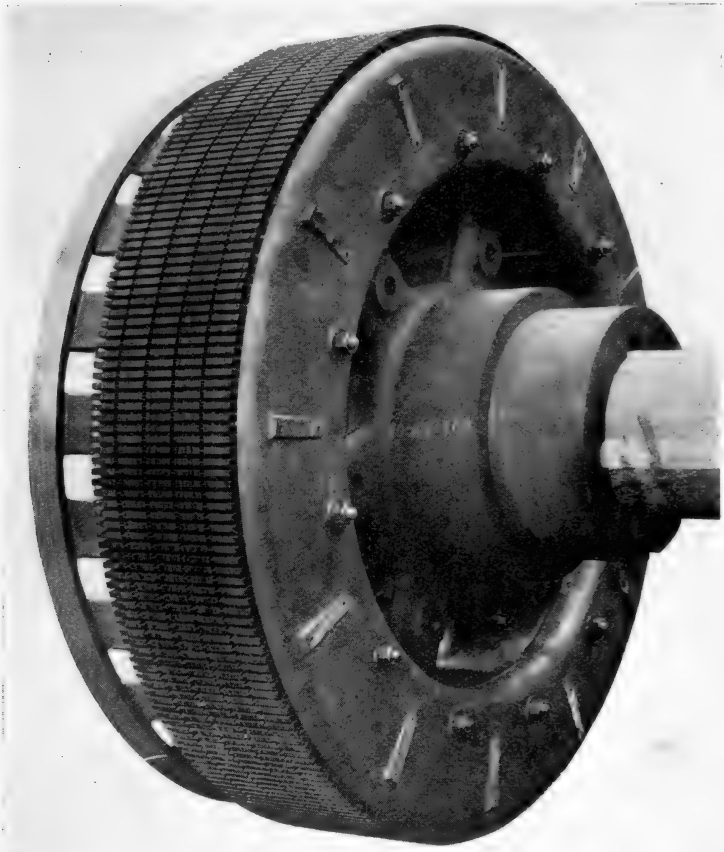


FIG. 97.—Complete Assembled Core of 10 pole 400 k.w. 100 r.p.m. Generator. Dick, Kerr & Co.

the discs are always laid with their burred side uppermost, the key-way will ensure that any discrepancies in the dies will be superposed. Cases have been noted where supposed unsatisfactory laminations have been found to be excellent when this precaution was observed in assembling. For the purpose of ensuring the assembling of the discs with the same side uppermost, just as they were punched, it is sometimes the practice to stamp out a small notch in the inner periphery of the disc, as shown in Fig. 90. This notch is sometimes punched in the key-way displaced from the centre, as in Fig. 89.

Experience will show the number of core plates of a given thickness which can ultimately be pressed together per centimeter of core length. Hence, when the suitable quantity has been

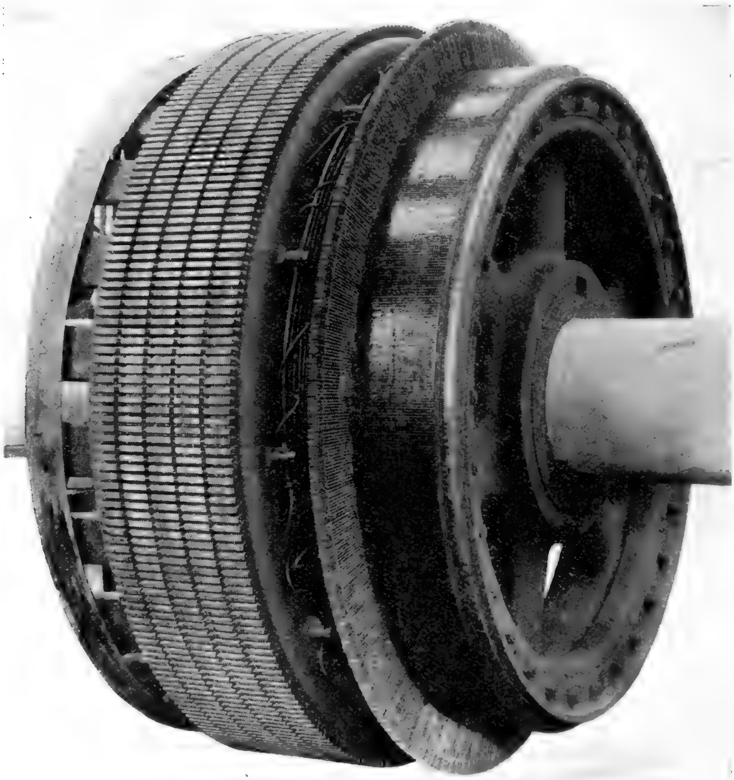


FIG. 98.—Assembled Armature Core of Fig. 97 with Commutator fixed. Dick, Kerr & Co.

assembled, a ventilating piece is laid on, and the assembling of the core plates is resumed. When the correct total number of core plates has been reached, the end flange is placed in position. In the case of large armatures, such as those of Figs. 85 and 86, bolts securing the two end flanges and core together may be employed to draw up the core to the correct dimensions; but it is preferable to obtain the necessary pressure by hydraulic power, and afterwards hold the core to these dimensions by the bolts.

The choice of method is, of course, dependent upon the factory equipment; but it may be said that in the case of small armatures hydraulic pressure is generally employed.

Where the external stator is the armature, as in Figs. 91, 92, and 93, the process is so closely similar to that above described as to make it sufficiently understood from the illustrations without further comment.

In Figs. 94 to 102 a number of completely assembled armature cores is shown.

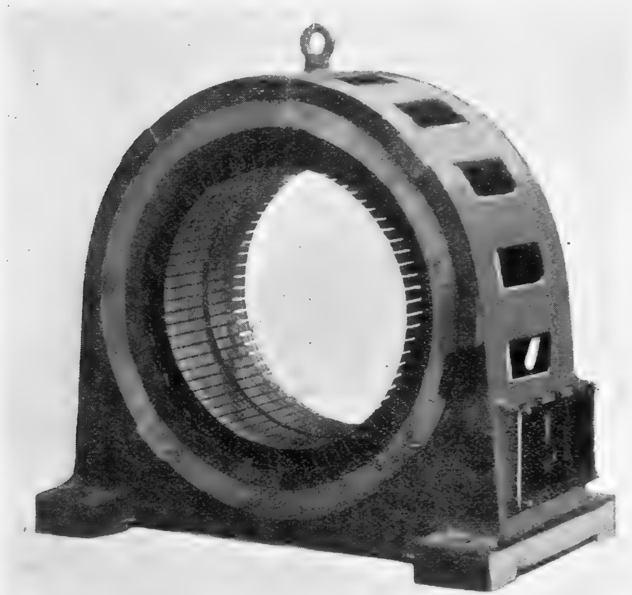


FIG. 99.—Complete Stator of Induction Motor by Allmanna Svenska Elektriska Aktiebolaget.

In work of this nature, the pressure desirable in assembling (whether obtained hydraulically or otherwise) is some 21 kgs. per sq. cm. (300 lbs. per sq. inch) gross surface of the laminations. If the pressures fall materially short of this amount, a thoroughly solid result cannot be ensured.

In a particular instance, a pressure of 10 tons is used in pressing up an armature core with discs of 300 mm. diameter.

In small armatures it is not customary to hold the core together with bolts passing through from one flange to another. One method is that shown in Fig. 332, Chap. XI., in which the

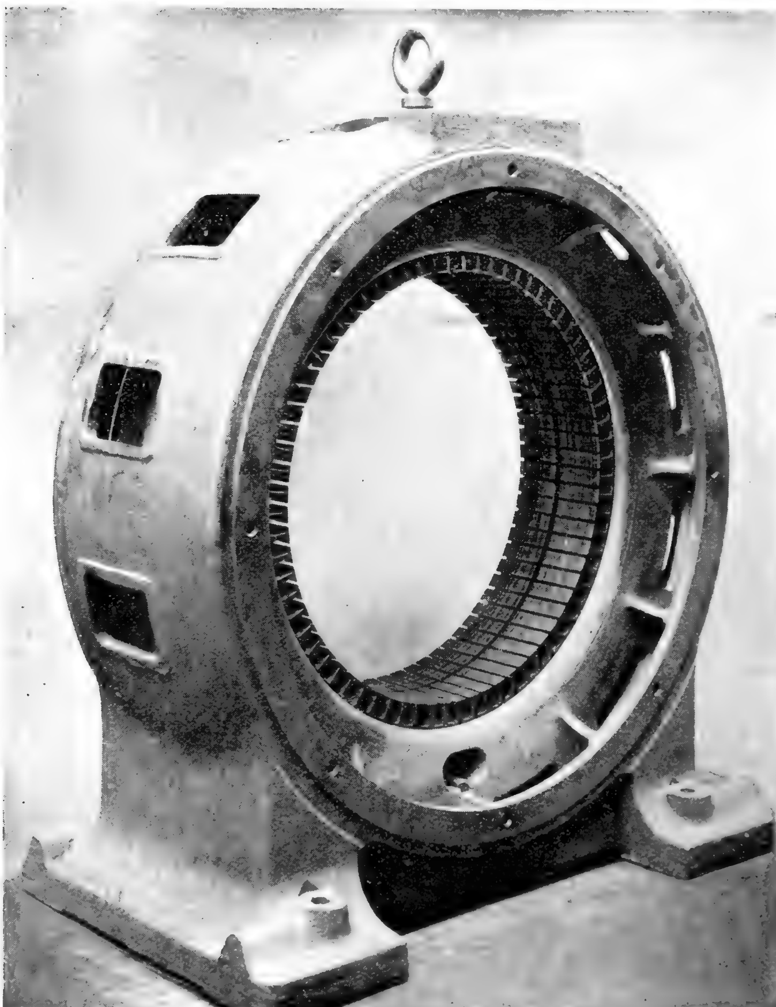


Fig. 100.—Complete Assembled Stator ready for Winding. Scott & Mountain.

removable flange is drawn up to the spider by short bolts. The use of circumferential keys, as shown in Figs. 69, 72, and 74 of Chap. III., may, in the case of small stationary armatures, be

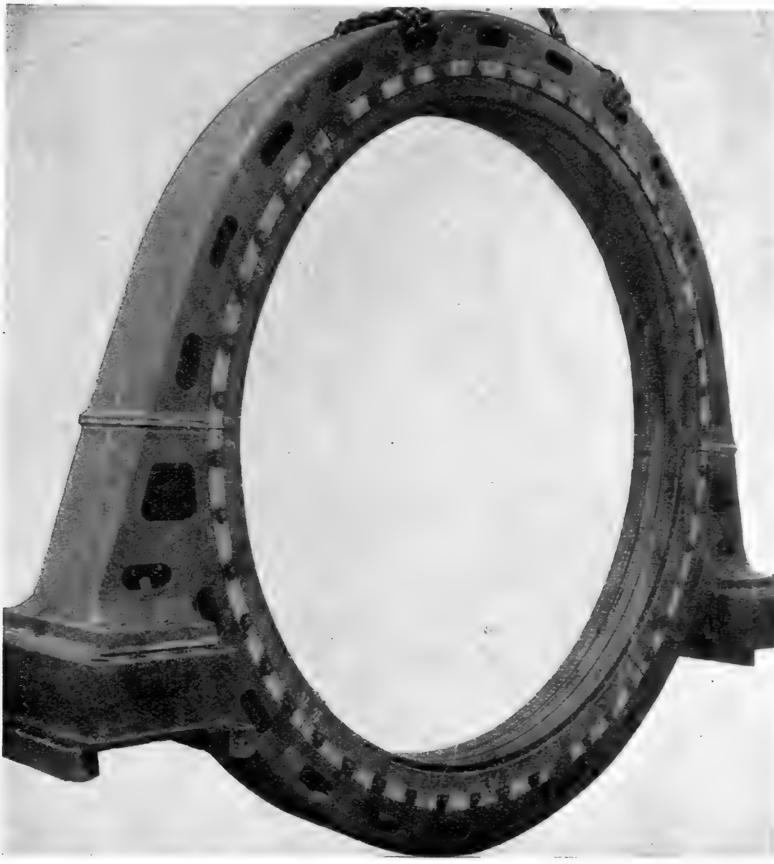


FIG. 101.—Complete Assembled Armature of large Generator. Allmanna Svenska Elektriska Aktiebolaget.

preferable to bolts. A construction which has been considerably employed for tramway motors is shown in Fig. 60, Chap. III., and consists in screwing the end flange on a threaded portion of the spider. In other cases it is screwed upon a threaded portion of the shaft, as shown in Figs. 61 and 64, Chap. III.

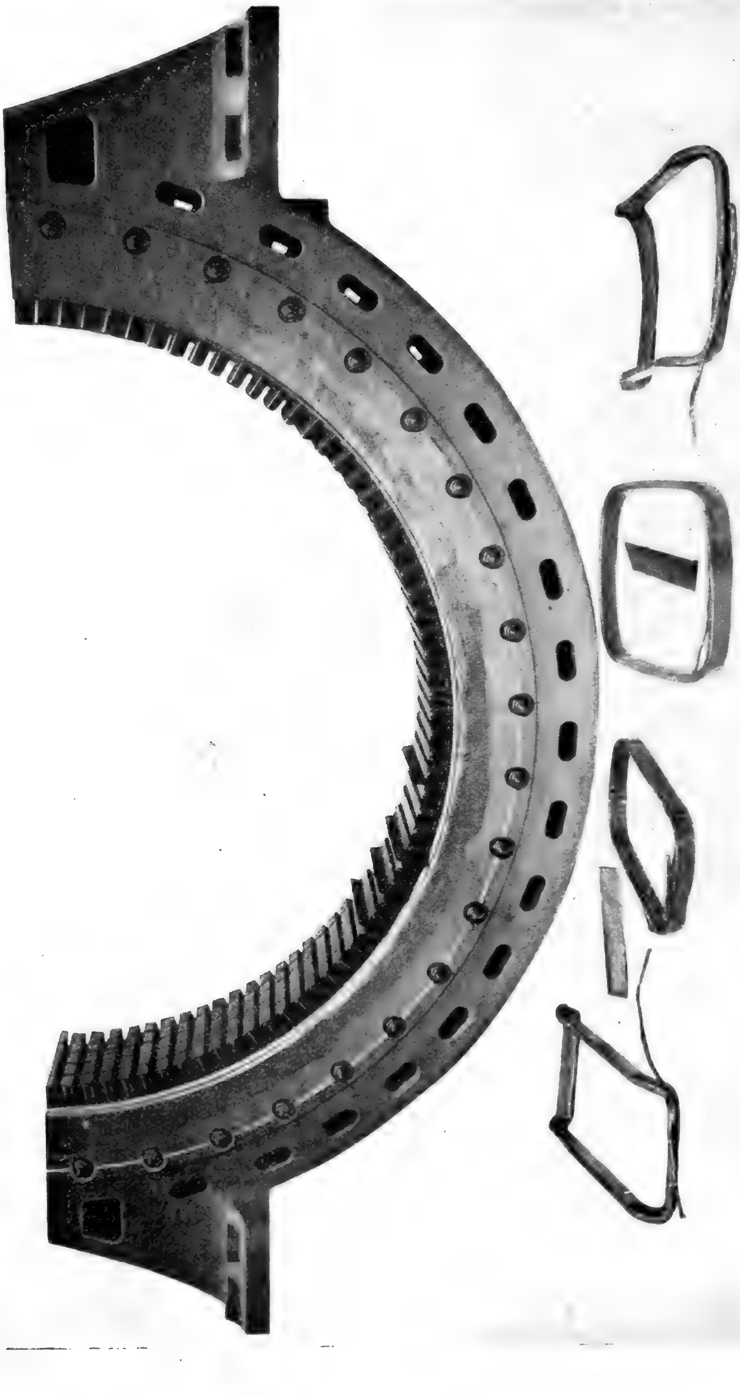


FIG. 102.—Lower half of complete Assembled Core of large Generator, showing some of its former Wound Coils. Dick, Kerr & Co.

CHAPTER VI

CONSTRUCTION OF SQUIRREL CAGE ARMATURES

The design and construction of squirrel cage armatures is comparatively a simple problem, as these pieces of apparatus are by far the least complicated types of armature occurring in any class of dynamo-electric machinery.

A squirrel cage armature, when completed, forms a very hardy structure, and it is largely on account of this and of its inherent simplicity that the squirrel cage induction motor recommends itself for such a large field of work.

So far as the spider is concerned, this does not differ much from the spiders used for ordinary continuous-current armatures, many types of which have already been referred to in Chap. III. As, however, with squirrel cage armatures there are no collector rings or commutator present, the spider may be made exactly symmetrical about the vertical axis of the machine. Thus a good spider for supporting the laminations of a squirrel cage rotor need only consist of a simple armed spider, with a pair of similar end flanges to clamp the laminations together.

For small motors, where the internal diameter of the rotor stampings is small, no spider is necessary, and the laminations are mounted directly on the shaft. This plan is sometimes applicable to rotors of larger diameter, where the laminations would have apertures stamped in them for purposes of ventilation, as in the illustrations in Figs. 64 and 84 on pages 67 and 81.

Fig. 103 shows a typical rotor construction on this plan. In this case the stampings are clamped up between two end flanges, one of which fits up against a shoulder on the shaft, and the other is screwed on to the shaft at the other end of the core; or it may be secured by a separate collar screwed on the shaft, and fixed by a grub-screw or a lock-nut. A method sometimes adopted in very small rotors is to make the end flanges with a small boss projecting away from the core, through which a pin is driven into a hole drilled in the shaft; or the flanges may be in this case secured by a grub-screw set in the boss. In shafts of any size it is, of course, inadvisable to drill a hole through the shaft, and hence this plan should not be employed.

Fig. 104 shows a good construction for rotors of moderate size. In this case the spider consists of a cast-iron boss with four radial arms, which project to the internal periphery of the stampings,

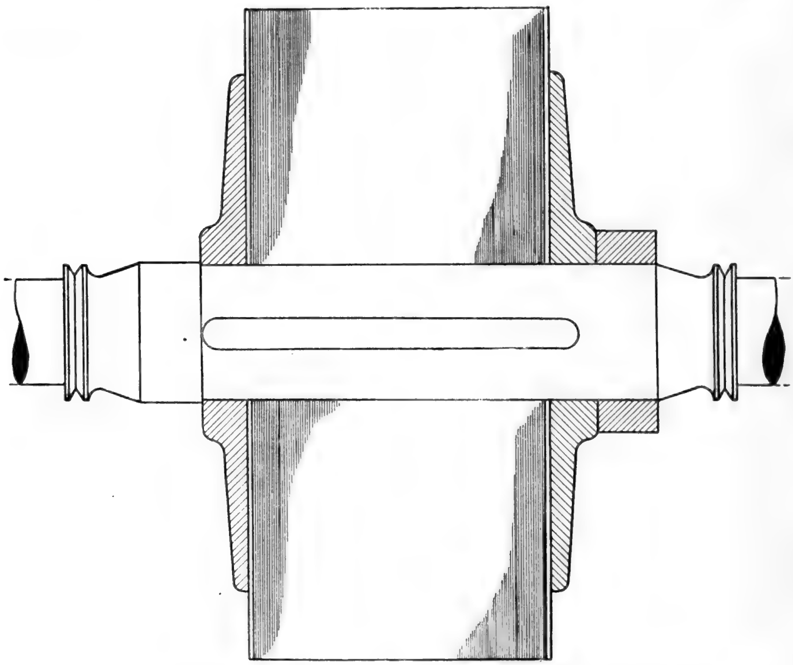


FIG. 103.—Drawing showing Typical Construction for small Rotor

the latter being secured to the arms by means of a square key; this engages in a key-way, milled longitudinally along the face of one of the arms, and a key-way punched at the internal surface of the stampings. The core is drawn up together between a pair of end flanges which are exactly similar, and may be cast from the same pattern, by means of four bolts which just clear the inside of the stampings. As a matter of fact, most of the methods of drawing up end flanges and securing stampings to the spider arms shown in Chap. III. may be used in this connection also equally well. A point to be noted about the construction in Fig. 104 is that there is no external cylindrical shell connecting the outside ends of the spider arms, and it is a good plan to dispense with this whenever possible, as it constitutes a needless obstruction to the ventilating air.

In very large rotors, however, a very massive and safe construction is necessary, and the lines indicated in any of the large spiders for continuous-current dynamos given in Chap. III. may be followed. As a good deal has already been said about large spiders for continuous - current armatures in that chapter, it is not necessary to dwell any further on the matter here.

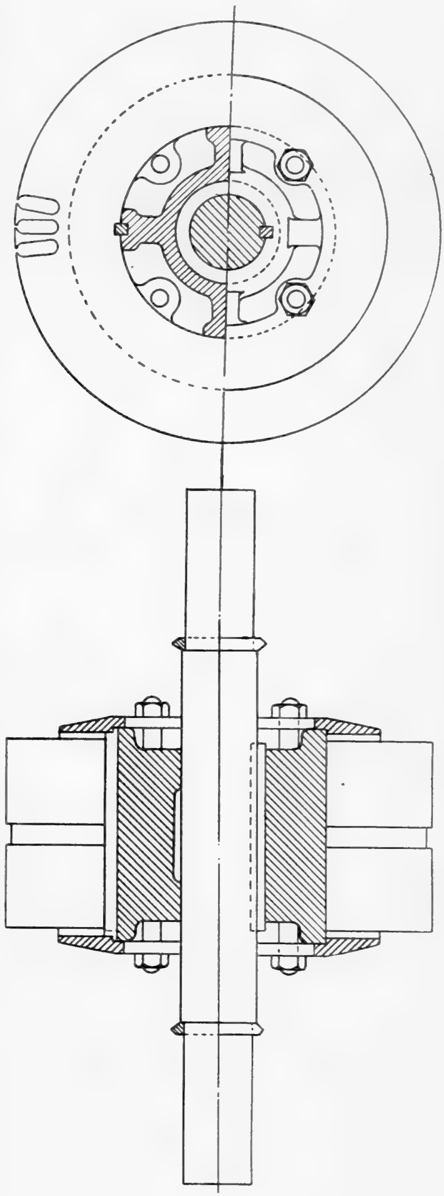


FIG. 104.—Drawing showing Construction for Rotors of moderate size

Turning now away from the spider, the chief variation in the construction of the squirrel cage armatures is in the methods of constructing and securing the end rings of the squirrel cage windings. There are practically no electrical considerations of importance in connection with the squirrel cage windings, the only necessity being to make a sound mechanical job of the winding. This is not a difficult problem, and there are many different types in use which are of thoroughly satisfactory character. The conditions to be met are, firstly, the fixing of the conductors in the slots; and secondly, the fixing of the end rings which short-circuit the bars at each end of the core. So far as the securing of the bars in the slots is concerned, this is easily accomplished by packing them tightly with a layer of some suitable insulating material such as red fibre or leatheroid.

The method of fixing the end rings depends somewhat on the shape of the section of the conductors. Below are given several

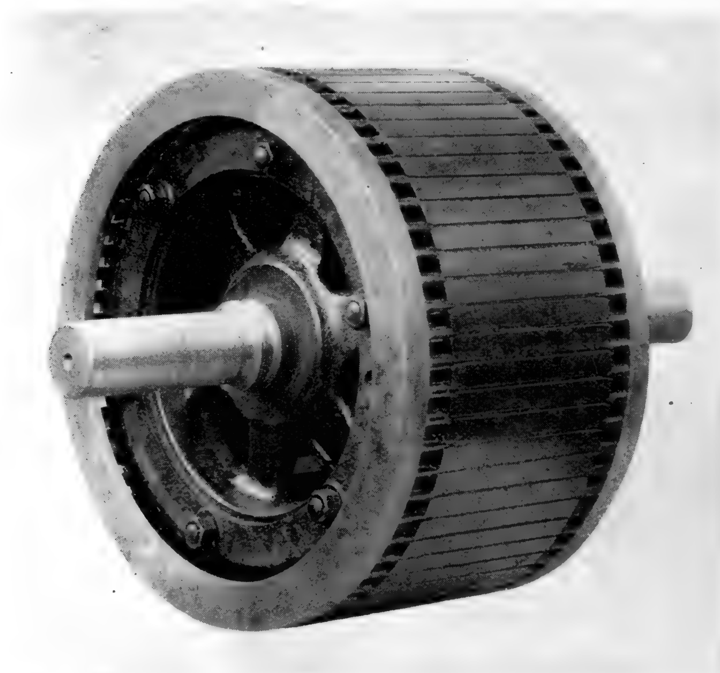


FIG. 105.—Squirrel Cage Rotor. Lancashire Dynamo Co.

good types of construction for both round bars and bars of rectangular section. In modern designs there is a tendency to increase the total amount of copper on the rotor for various reasons in connection with the design and performance of the motor, into a discussion of which we have no occasion to enter now. In such designs the total cross section of each bar becomes larger and larger, and it is necessary to use slots having a radial depth great compared with their width, in order to get room for the required amount of copper on the periphery.

In cases where a round bar, and, consequently, a circular slot, can be employed, any of the few following constructions is quite efficient. Fig. 105 shows a photograph of a very strong construction employed by the Lancashire Dynamo and Motor Company for their squirrel cage rotors, and Fig. 106 a sectional sketch through the end ring of the same construction. The end ring is

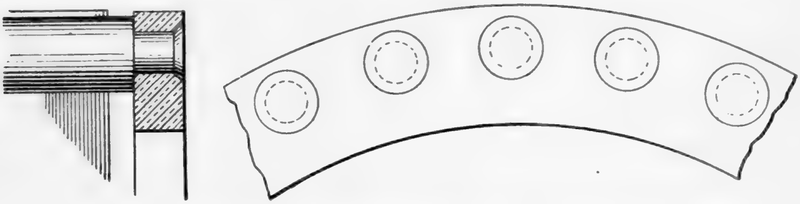


FIG. 106.—Typical methods of fastening end rings to circular Rotor Bars.

in this case drilled with a number of holes equal to the number of slots on the rotor, these holes being of rather less diameter than the body of the rotor bar. The latter is turned down at its end to a diameter which will just make a good fit into the holes in the end ring. The holes are counter-sunk on the outside face of the ring, and the ends of the bars riveted over, as indicated in Fig. 106. The bars may also be sweated at their joints with the end ring as a further precaution for good contact. Then after

FIG. 107.—Typical methods of fastening end rings to circular Rotor Bars.

riveting up the bars, the rotor is mounted in a lathe and the end rings faced up, giving a well-finished job, as may be seen from Fig. 105, in which the riveted ends of the bars are hardly discernible. This construction is excellently adapted to withstanding very high temperatures, and is therefore very suitable for motors which are liable to be subject to starting against a heavy torque, in which cases there is a large loss in the squirrel cage windings, and liability to high temperature rises at starting.

Fig. 107 shows another method which is almost as good as the previous one, and is perhaps more useful when the cross section of the end rings is not very large, as will be seen from the sketch.

The bars have a slot milled or punched out on their ends, into which is pressed a ring or a circular strip of metal constituting the end ring, the joints being sweated up.

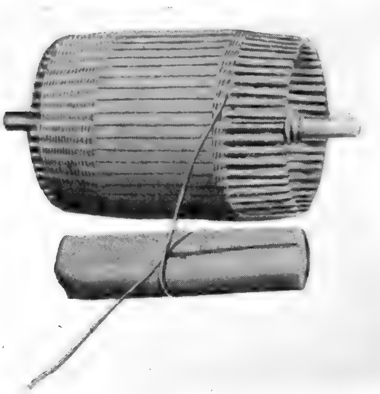


FIG. 108.—Winding Squirrel Cage Rotor. Allmanna Svenska Elektriska Aktiebolaget.

A type of construction differing from both of the above chiefly in the absence of any machining, either to the bars or end rings, is shown in Figs. 108, 109, and 110. This method is used by the Allmanna Svenska Elektriska Aktiebolaget, of Sweden, and is the invention of Ernst Danielson.

This construction affords good facilities for cooling. The end windings, and the individual wires constituting the end connections, are sometimes proportioned

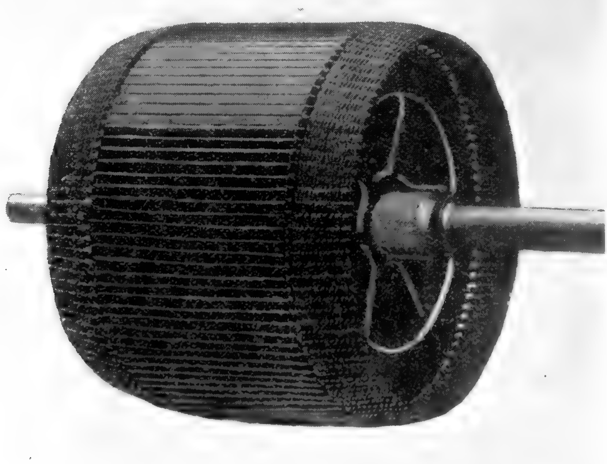


FIG. 109.—Finished Squirrel Cage Rotor by Allmanna Svenska Elektriska Aktiebolaget.

for current densities as high as from 2500 amperes to 3500 per sq. cm. A finished winding of this type is shown in Fig. 109, and the method of winding will be clear from Figs. 108 and 110. The bars are cut from hard-drawn copper wire to the required length, and, after being straightened, are driven in the slots from one end with a wrapping of fibre for packing. The end windings are carried out by means of soft copper wire of small diameter, which is twisted round each conductor in succession until nearly the whole of the overhanging portions of the bars has been filled up with these windings.

The end portions of the windings are then well sweated up with a blow-lamp, or by heating with a gas ring and running in solder, which secures the fine wires to the bars both mechanically and electrically. One good feature of this winding is that it permits of the resistance of the end rings being fairly easily adjusted; for instance, if after the motor has been installed it is found that a higher starting torque is required, it is a comparatively simple matter to take off a few turns of the end winding, thus increasing its resistance, and hence the starting torque.

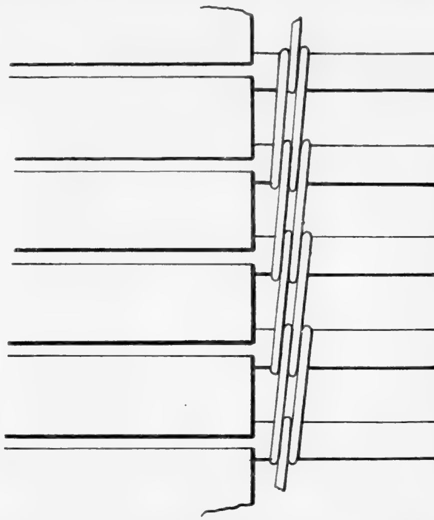


FIG. 110.—Drawing showing section of Winding of Rotor in Fig. 109.

In the cases of Figs. 106 and 107 it would be necessary, in order to increase the end ring resistance, to mount the complete rotor in a lathe and turn some of the end ring away; and it may here be pointed out that the end ring should be arranged so that this is possible without interfering with the rotor bars. Thus in Fig. 106 a considerable portion of the section of the end ring projects radially inward, and may be turned smaller at will.

Before leaving rotors with round conductors, there is another interesting construction depicted in Figs. 111 and 112. This is a construction used by the Alioth Company of Switzerland. A front view of one of the end rings is shown in sketch A in Fig. 112. The rotor bars, after emerging from the slots, are bent down radially. The actual end ring is of the shape indicated in sketch B, the projecting pieces being bent over the end of the bars, as indicated in sketches C and D, the upper row of projecting teeth being bent to the right hand, and the lower row to the left, and then all the joints are soldered up. In connection with Fig. 111, one will notice the three large vanes projecting from the end of the core. Vanes are employed rather extensively nowadays, their object being to act as ventilating fans, and to churn air through the machine for cooling purposes. Similar blades will be noticed in Fig. 116; they should not, however, be of too large a size, as this will materially add to the windage losses of the motor. It is probable that the blades in Fig. 111 are rather larger than would be desirable, especially if the speed is high. In

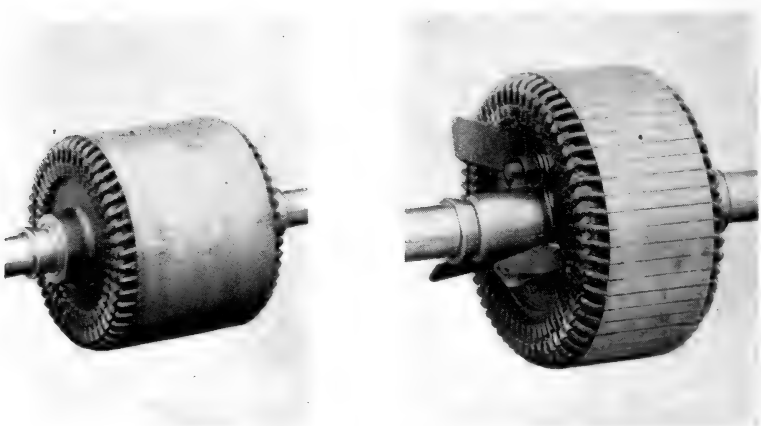


Fig. 111.—Squirrel Cage Rotors by Alioth Co.

latest practice, it is almost universal to locate the end ring on as large a radius as practicable; thus it is situated directly opposite the ends of the slots, as in all the above constructions. A method which was used earlier, but which does not obtain largely nowadays, was to bring all the conductors down radially to a small end ring fitting on the shaft. Such a construction is shown in Fig. 113, which represents an old design of the Allmanna Svenska Elektriska Aktiebolaget. In such a construction as this, a high resistance end ring is not easily obtained in a case where it is necessary, as the periphery of the end ring is very much restricted, although the bars are themselves long, and of higher resistance. In addition to this, the structure is not so simple a mechanical job as others of the above methods.

Now we come to cases where the rotor conductors are of rectangular cross section.

Fig. 115 illustrates a good method, which is similar to that

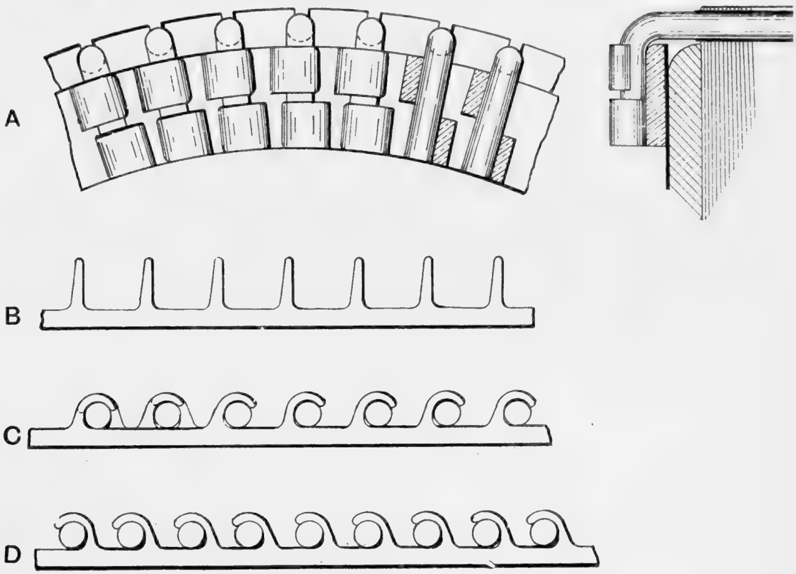


FIG. 112.—End Rings used by Alioth Co.

illustrated in Fig. 106. Here the end ring has a number of slots milled out from the outer circumference, into which the bars emerging from the slots fit and are sweated. The slots may be cut on a milling machine with a divided head, and, provided this item of the process can be executed fairly cheaply, the whole method is comparatively inexpensive.

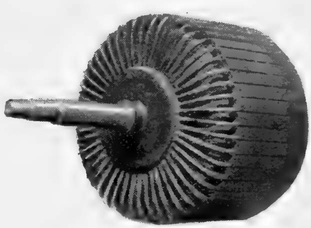


FIG. 113.—Squirrel Cage Rotor by Allmanna Svenska Elektriska Aktiebolaget. (Old Type.)

The method employed by the Westinghouse and Thomson Houston Companies, is to screw the ring on to each bar individually, as shown in Fig. 115. This makes a rather longer job than the method of Fig. 114, but it renders the end rings absolutely safe against coming away from the bars, as may occur where solder alone is relied on at the joints.

The photograph of a rotor carried out on this plan is shown in Fig. 116. The construction of the rotor spider and end flanges is here worth noticing. The spider follows the lines of Fig. 104, thus leaving the internal surface of the core almost completely exposed. The bolts connecting the end flanges just clear the interior of the core, as in Fig. 104. Each end flange carries three projecting vanes for driving the air through. In this rotor

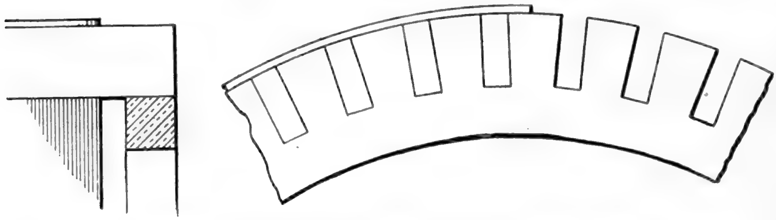


Fig. 114.—Typical methods of fastening end Rings to rectangular Rotor Bars.

there are no ventilating ducts in the core; and the effectiveness of the end vanes, and of the open type of spider, would be much increased if one or two ventilating ducts were present, as the air driven in by the blades would circulate through the core ducts and effectively cool the body of the motor.

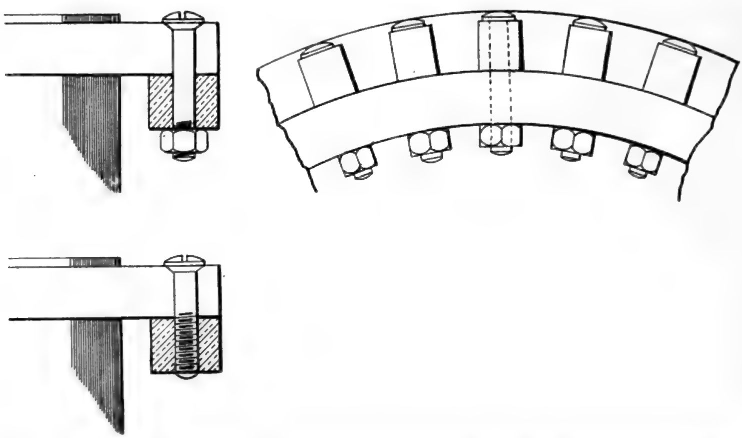


Fig. 115.—Typical methods of fastening end Rings to rectangular Rotor Bars.

A matter of great importance in connection with induction motor squirrel cage armatures (and, indeed, any induction motor rotor) is the accurate machining of the external surface of the core necessitated by the very small air-gaps employed. The values employed for the radial depth of air-gap, between the surface of the stator and rotor laminations, are shown for various diameters in the following table, which represents the writers' average practice.

TABLE X.

AIR-GAP DEPTH FOR INDUCTION MOTORS.

Diameter at Air-gap in cms.	Radial Depth of Air-gap in mm.
20	0·8
30	1·0
40	1·1
50	1·2
60	1·4
80	1·6
100	2·0
200	3·0

For rotors of smaller diameter than 20 cm., which are used in very small ratings, air-gaps even smaller than 0·8 mm. have been used, and in some cases as small as 0·5 mm. To obtain accurate machining, the surface of the rotor iron is frequently ground up by an emery wheel rotating and mounted on the slide rest of the lathe in which the rotor itself is being machined, as in Fig. 117.

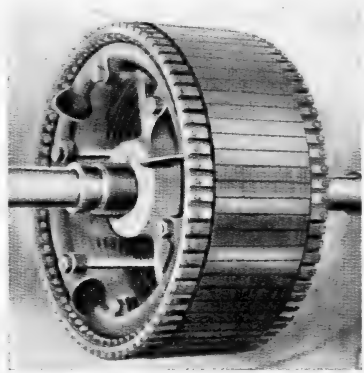


FIG. 116.—Squirrel Cage Rotor, showing Construction of Rotor Spider and Screwed End Rings.

It is important for the air-gap length to be constant at all points around the periphery, and inequalities in the air-gap will be more marked and serious when the air-gap is small, as is the case with induction motors. When the bearings of the motor begin to wear there is a danger of the rotor fouling the stator core at the bottom, and it is not now uncommon with induction motors to make the end brackets which carry the bearings adjustable, so that the rotor may be maintained central with regard to the stator, to compensate for any wear of the bearings.

These small gaps are employed for induction motors for reasons connected with the electrical design and qualities of the motor, prominent among which are the power-factor, and the maximum permissible value for the current at no-load. For the same reasons semi-closed slots (or, sometimes, totally closed slots) are generally used, wide open slots being very rarely employed for squirrel cage motors.

If the slots are totally closed, it is necessary for the iron bridge over the mouth of the slot to be very thin; and this necessitates die-work, so that the slot mouths shall not break open in places when the rotor core is turned or ground up.

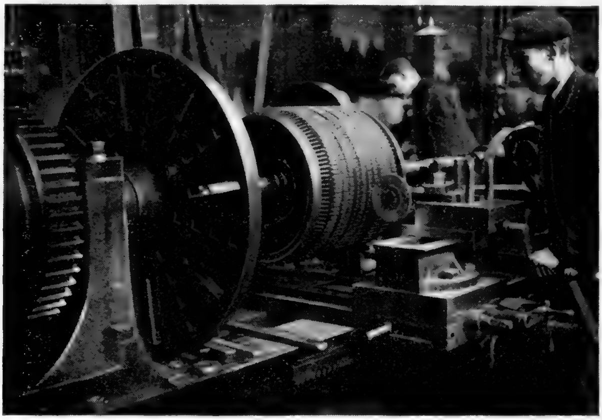


FIG 117.—Grinding Surface of Induction Motor Rotor.

Fig. 118 shows a group of typical slots for squirrel cage rotors; types *a*, *b*, *c*, and *d* are quite common. The slot shown in sketch *e*

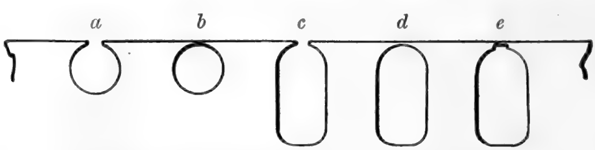


FIG. 118.—Types of Slots used in Induction Motors.

has been used to obviate the trouble just referred to; in this case the bridge across the slot mouth is filed down to a very narrow thickness, from the inside of the slot, after the core is assembled and machined.

Some notes on the punching of slots and core plates for induction motors will be found on pp. 42–46, Chap. II.

CHAPTER VII

COMMUTATOR CONSTRUCTION

In the present chapter it is proposed to trace the building of the commutator, beginning with the raw material and ending with the finished commutator.

While tracing the progress of building, general remarks on the materials used and on their properties are inserted; in the latter parts of the chapter some examples are given illustrating typical modern constructions for commutators to fill various requirements, together with notes on their construction and design.

Only the softest and most flexible mica should be used between segments; green shades of mica, and amber-coloured mica, are generally most satisfactory. Amber-coloured flexible Canadian mica has been found specially suitable; other grades of Canadian mica are unsatisfactory. In some quarters, green shades of mica are preferred, and it is claimed that they are softer and more flexible than the amber mica. The colour alone cannot be depended upon as a guide to the softness. The white mica from North Carolina, and the mica from India, are often too hard for the purposes of segment insulation. Softness is far more important than high insulation quality; thus while white mica has the highest insulation resistance, it is altogether unsuitable for insulation between segments. In no case should a mica be adopted for this purpose without careful tests of its mechanical quality. The mica end rings, however, may be made of almost any good quality of mica, as for this purpose softness is, of course, of no importance. India mica is often employed for the end rings. The shellac or other cementing medium employed in building up the mica segments from the flakes of mica, must be thinned and sparingly applied, and the plate built up in this fashion must be pressed and heated (preferably at one operation) to expel from the plate all but an extremely thin film, barely enough to hold the components

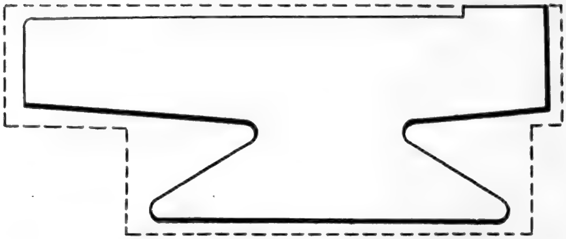


Fig. 119.—Outline of Commutator Segment.

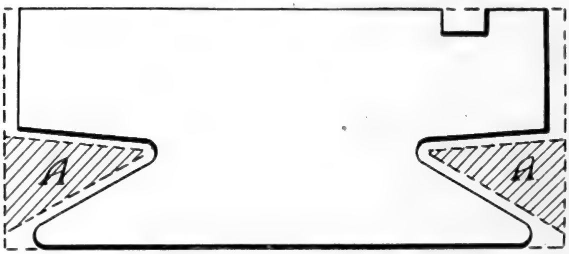


Fig. 120.—Outline of Commutator Segment.

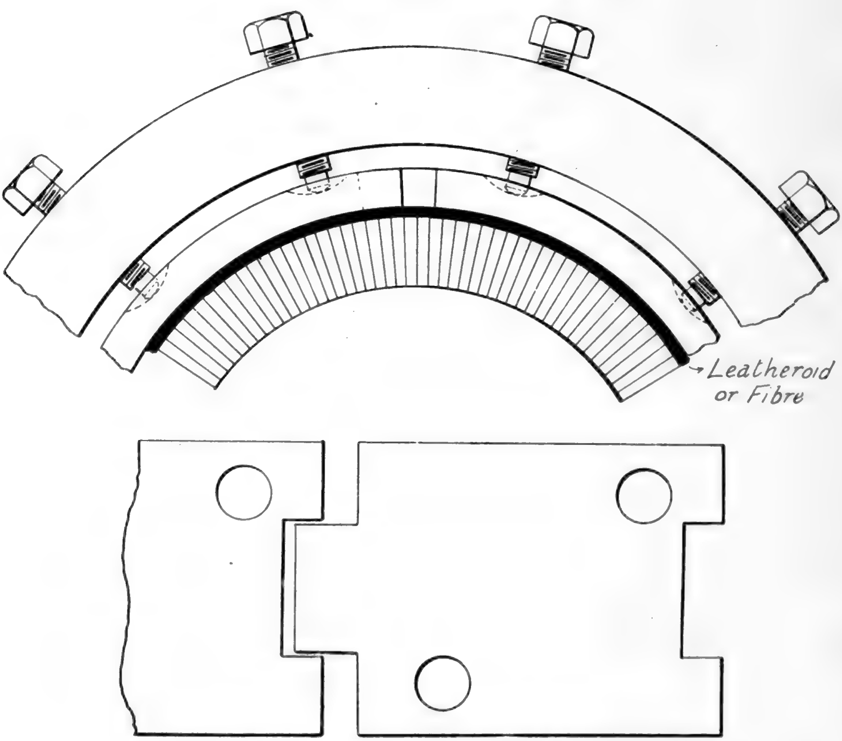
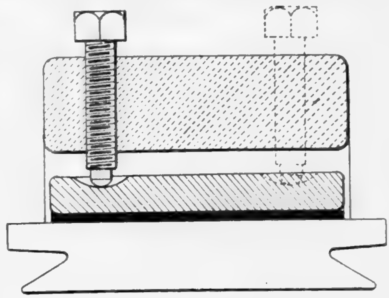


Fig. 121.—Commutator Building Rings.

together. As cementing medium, shellac and copal varnishes have been used with good results. In the building up of mica plates, the pressure should be applied gradually, being increased as the baking process proceeds, otherwise the component pieces of mica are apt to slip and slide apart. The plate thus formed is then sawn or sheared slightly larger than the commutator segment; it is afterwards tested and pressed, and is finally put through a milling machine, which reduces it, in the case of large machines, to a uniform thickness of about 0·7 mm. The plates must be of extremely uniform thickness—a variation greater than 0·05 mm. not being permissible. The segments should be of hard drawn copper, which are cut up into pieces the length of the commutator. To save time in machining the ends of the segments, they are often, in the case of large commutators, sawn out to the shape indicated by the dotted line in Fig. 119; or in smaller commutators the portions marked A in Fig. 120 are punched out in a vertical slotting machine. The use of forged segments has sometimes been found unsatisfactory; but when drop-forged segments are used they are forged to the required shape, and often with the lugs in one piece with the segment. All the segments for the same commutator must come from the same stock, and in any case must be of uniform quality as regards hardness. The segments are first assembled on end, inside massive steel rings (two such rings are often used) studded with stout bolts bearing against clamping segments, as shown in Figs. 121 and 122.



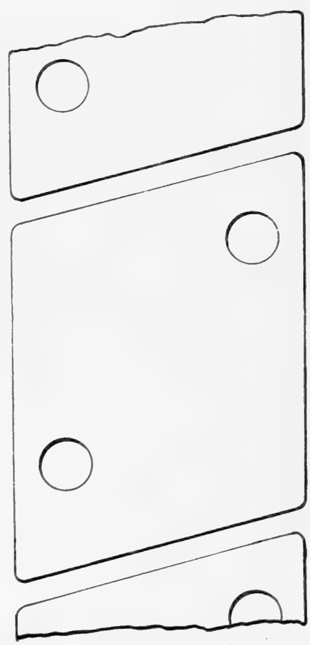


Fig. 122.—Commutator Building Rings.

Soft sheet leatheroid or fibre 3 mm. thick, and arranged as shown in Fig. 121, separates the clamping blocks from the copper segments, so that short circuits may be detected by a testing-lamp or magneto bell. These are all mounted together, with the lowest ends of the copper segments and insulations resting upon a horizontal surface plate. For the best results, the copper segments and mica segments, when thus rough, must have their lower ends constitute approximately true surfaces, normal to their outer surface, otherwise the segments when first loosely assembled will not come into even approximately true alignment, but will tend to stand as roughly indicated in Fig. 123.

FIG. 123.—Showing objectionable and defective arrangement of Segments.

After the copper and mica segments are all assembled in place, they should next be squared up true to a steel square which is placed inside on the surface plate, as shown in Fig. 124. When all the segments have been trued up as indicated, the clamping ring bolts should be tightened up, each a little at a time, a quarter or even only an eighth of a turn each time according to

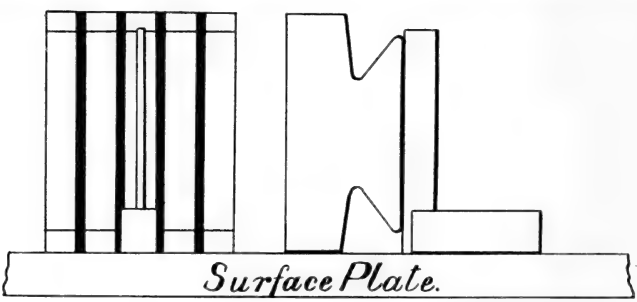


FIG. 124.—Squaring up Segments.

the size of the commutator. The distance between the outside of the clamping blocks and the inside of the clamping ring may be gauged by a pair of inside calipers, as indicated in Fig. 125. At this stage great exactness must be obtained, as otherwise the surface will have oval or flat places; but by frequently calipering the distance between the clamping blocks and the ring, and by taking time in tightening the clamping blocks by but a very little each time, a high degree of exactness may be attained.

Instead of the arrangement of assembling rings shown in Figs. 121 and 122, a method is sometimes used of pressing a single heavy steel ring, by hydraulic pressure, over the commutator, making a very tight fit. This is more applicable to small standard

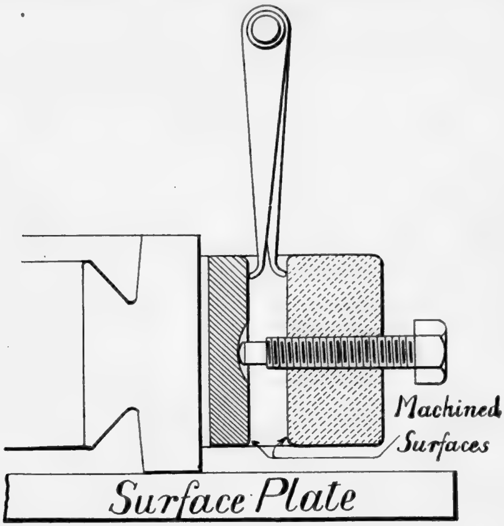


FIG. 125.—Gauging.

commutators, but has occasionally also been used for large commutators, as shown in Fig. 128, which illustrates the assembling of a 750 k.w. commutator by this method. Fig. 127 shows the

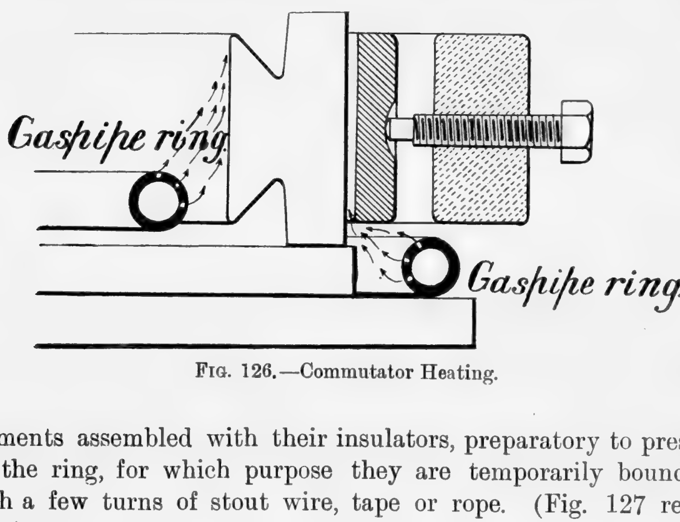


FIG. 126.—Commutator Heating.

segments assembled with their insulators, preparatory to pressing on the ring, for which purpose they are temporarily bound up with a few turns of stout wire, tape or rope. (Fig. 127 relates to a 75 h.p. commutator.)

Another method, suitable for small standard commutators, is illustrated in Fig. 129, which is self explanatory.

Fig. 127.—75 h.p. Commutator before pressing into the Building Ring. Vickers, Sons & Maxim.

For applying heat, perforated gas-pipes are bent in a circle to correspond to the inside and outside surfaces of the ring of segments, the perforations being on the side of the pipes facing

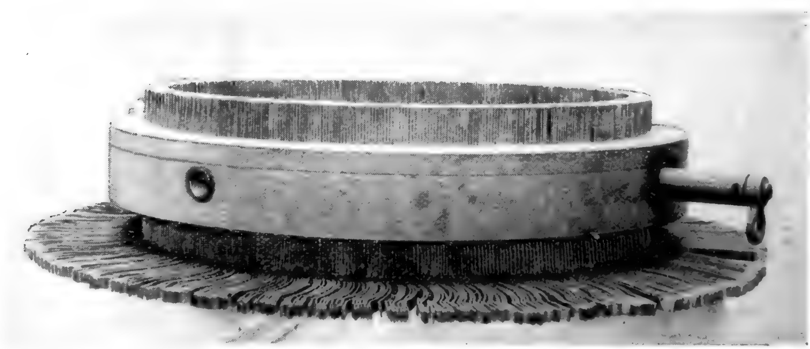


Fig. 128.—750 k.w. Commutator in Building Ring ready for turning. Vickers, Sons & Maxim.

the copper, as indicated in Fig. 126. A suitable temperature is attained by adjusting the relative supplies of gas and air. The copper should be heated to a temperature of some 150° Cent. The clamping blocks should be tightened, little by little, by means of the radial bolts, as the heat drives the cement out from the mica.

It is of importance to supply the heat slowly, as, otherwise, the

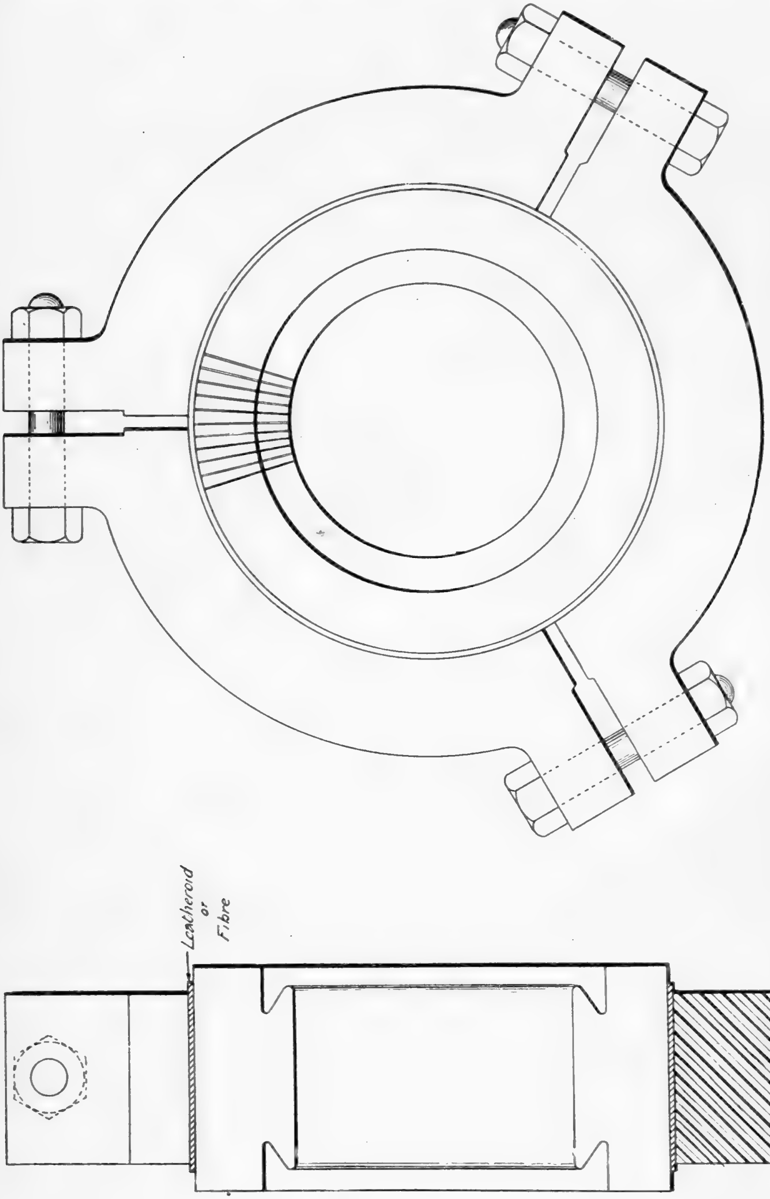


FIG. 129.—Split Building Ring for Small Standard Commutator.

moisture sweated from the iron and copper from the internal surfaces (the sweating from the external surfaces is, of course, freely dissipated) is absorbed by the excess cement, and may lead to acid formations, which if retained anywhere—as, for instance, in cavities—may ultimately cause disintegration of the mica insulation, especially if any trace of oil ever gains access to these parts.

Where, for a special commutator, it is too expensive to provide the rings of gas-pipe, the heating may be accomplished, though less effectively, by individual Bunsen burners; but this takes longer, and is far from satisfactory. From one to two hours application of the heat is generally sufficient when rings of gas-pipe are employed, and during this period the gas-pipe should be

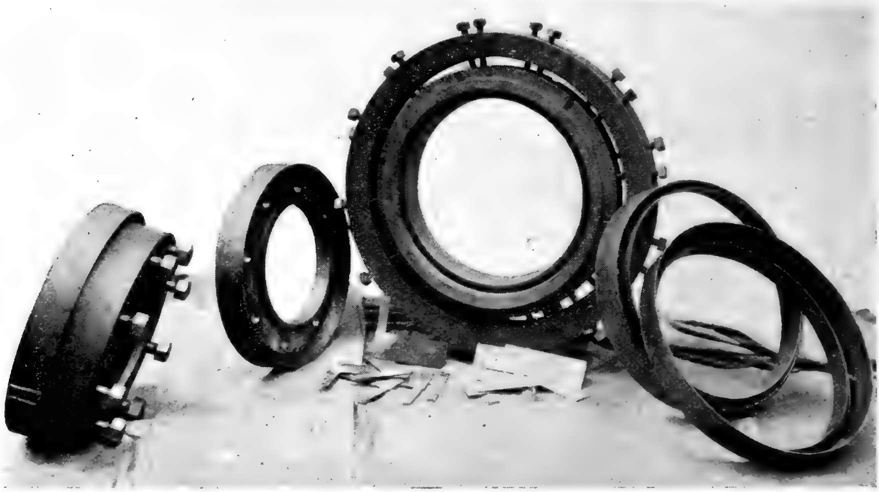


FIG. 130.—Machined Commutator ready for Bush, showing Building Rings and parts.

frequently slightly shifted to avoid concentrating the heat upon any particular places, and to avoid destroying the leatheroid or fibre insulation. It is a good plan to line the inner surface of the segments with sheet iron, to prevent the flame from carbonising the cement in the mica strips. One should continue to uniformly and gradually tighten up the clamping blocks during the cooling process. When cold, the V-grooves at the ends of the segments are turned on a boring mill, and the segments are then tested for short circuits. Fig. 130 shows the commutator after the V-grooves have been turned in the ends, the commutator still being held in the assembling rings, of the type shown in Figs. 121 and 122. On the right-hand side of the figure may be seen the mica V-rings, and on the left the commutator bush and clamping end plates. Fig. 131 shows a small commutator after machining the interior and ends, assembled in a single ring as in Fig. 128.

The end clamping rings with their insulations are then put in place, adjusted, and tightened up, preferably by the application of hydraulic power. Fig. 132 illustrates the process of pressing

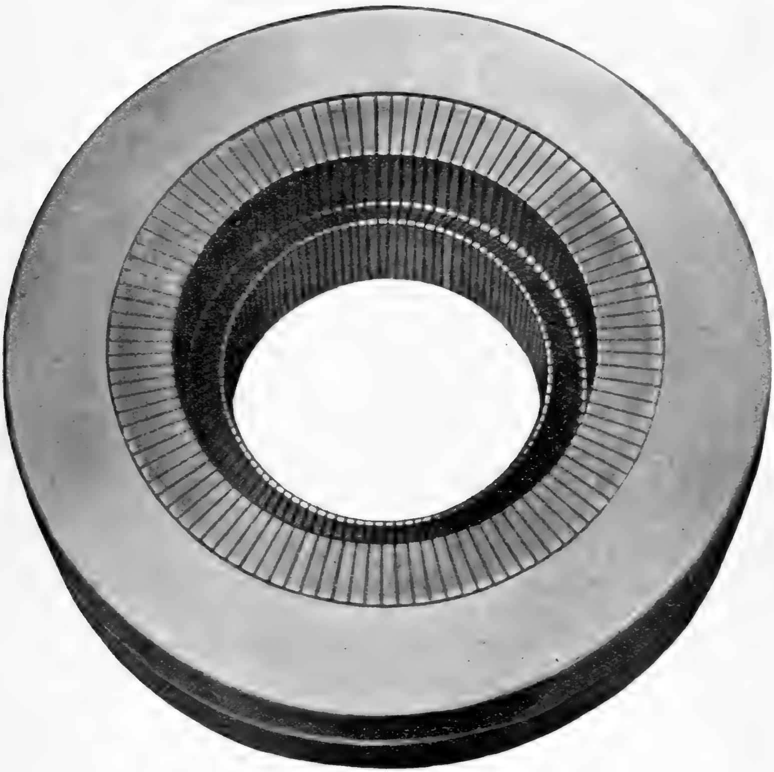


FIG. 131.—Machined Commutator in Building Ring ready for Bush

the V end rings on to the commutator under hydraulic pressure. The bolts which hold the end rings together are tightened at the same time, so that, when removed from the press, the commutator is a rigid structure. With the increasing size of commutators there is a general tendency to dispense with hydraulic power for this process; but it is, nevertheless, of advantage—at any rate up to diameters of 2 feet or more—though the equipment is expensive. For a 30-inch diameter

Fig. 132.—200-ton Press for squeezing Commutators. Vickers, Sons & Maxim.

Fig. 133.—Commutator Assembled and ready for Armature.

commutator, 60 tons pressure should be applied, or, say, 1200 lbs. per inch of circumference for a very rough rule. For very large diameters, some firms have employed massive solid steel rings, with slightly conical internal surfaces, and have forced these over the segments by three presses, equidistant about the periphery. But this is now generally abandoned, and the radial pressure is, for large commutators, practically universally applied by means of an external steel ring provided with numerous radial bolts, bearing on clamping blocks as already described; and where hydraulic pressure is employed, it is for the purpose of tightening the end clamping rings. Where hydraulic pressure is dispensed with for this purpose, it is the more important to have numerous massive bolts for drawing up and permanently holding the end rings. After again testing for shorts and grounds, the external clamping rings are removed. The commutator is now again heated by means of the outside ring of gas-pipe. A still further amount of cement is thus driven out, and the bolts retaining the end clamping rings are gradually tightened up, a very little at a time, during the process; or, and preferably, the hydraulic pressure is applied before and during each tightening of the bolts. The tightening is continued during cooling. A test for shorts and grounds is again made; the surface is then turned roughly and the insulation again tested. The commutator is now in the state shown in Fig. 133, and is ready to be bolted on to the armature spider, preparatory to connecting it up to the armature windings, after which the commutator surface undergoes final machining. A good plan sometimes employed, consists in using segments with the internal edges rounded, as shown in Fig. 134, the internal surface in this case not being turned. This construction gives a long leakage path at the bottom, from segment to segment; and as the inner surface is so inaccessible, it is thought that the precaution is desirable. It is not so obvious that this is the case, since the corners afford lodgment for dust; and hence the interior must be made inaccessible to dust, and carefully cleaned out before being closed in. The mica end rings of a commutator should be from 1·5 to 3·0 mm. thick, according to the voltage and size of the commutator. Both for the end rings and the segment mica, the secret of success rests largely upon the application of heat, say, 200° Cent., whenever pressure is used. This facilitates the exudation of all but a minimum residue of

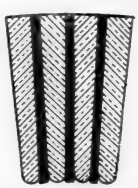


FIG. 134.—Sketch showing rounded edges of Commutator Segments.

cement and moisture, and assists in making the structure compact and solid. It must, however, not be carried to such an extent as to carbonise the cementing varnish; for in this case any oil in proximity to the mica insulation would be absorbed, and ultimately lead to the disintegration of the mica plates. Some firms supply built-up mica plates, for which they claim that the adhesive matter in the finished plate does not exceed 1·25 per cent. of the

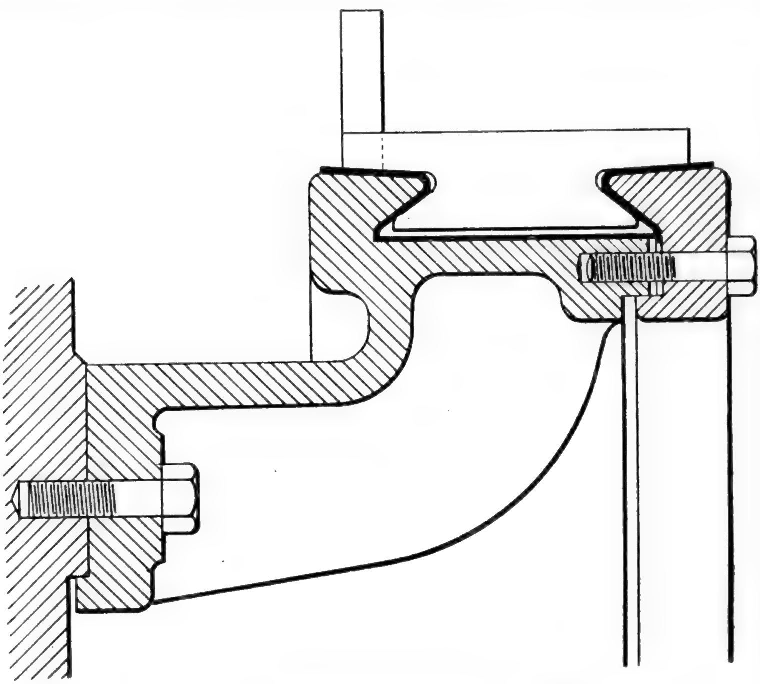


Fig. 135.—Typical modern large Commutator Construction.

weight. The product of different manufacturers varies greatly in this respect, and comparative tests of various qualities as regards softness, percentage of adhesive matter, and heating, when subjected to a high potential test from side to side, are very desirable before determining upon the quality to be employed.

As before stated, with the rapid increase in the size of the commutators, the use of hydraulic pressure has been more or less given up; it would, nevertheless, appear to be of advantage in the interest of obtaining the greatest possible solidity. Hydraulic pressure should also be employed in pressing up the armature laminations, and machinery suitable for both these purposes is to be recommended. The temporary external clamping rings, bolts, and segmental plates should be of the most massive construction, as roughly indicated in Figs. 121 and 122. This should also be the case with the permanent end rings and the commutator spider. The depth of the copper segment should be very liberal, not with a view to permitting repeated turning or

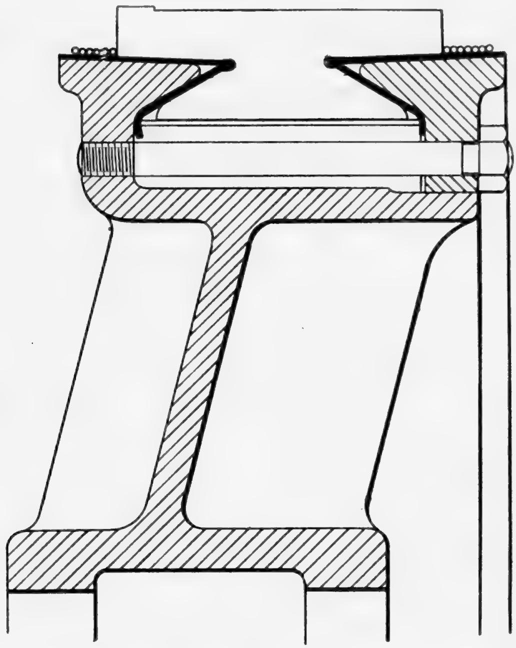


FIG. 136.—Typical Commutator Construction for large Traction Dynamo.

grinding of the commutator surface (this becomes superfluous in good designs), but with a view to mechanical strength. The radial depth of copper below the inner corners of the end clamps should, therefore, be very liberal. The segments should be repeatedly and vigorously tapped during the application of the pressure and the heating. A construction with a massive commutator spider projecting from the armature spider is to be preferred, both on account of the superior ventilation and of the relative rigidity of armature conductor and commutator segments. A good modern construction on these lines is indicated in Fig. 135. Fig. 136 shows an alternative construction for large commutators. Unlike the construction of Fig. 135, this commutator is built on an armed spider, which is subsequently mounted on an extension of the armature spider—a plan

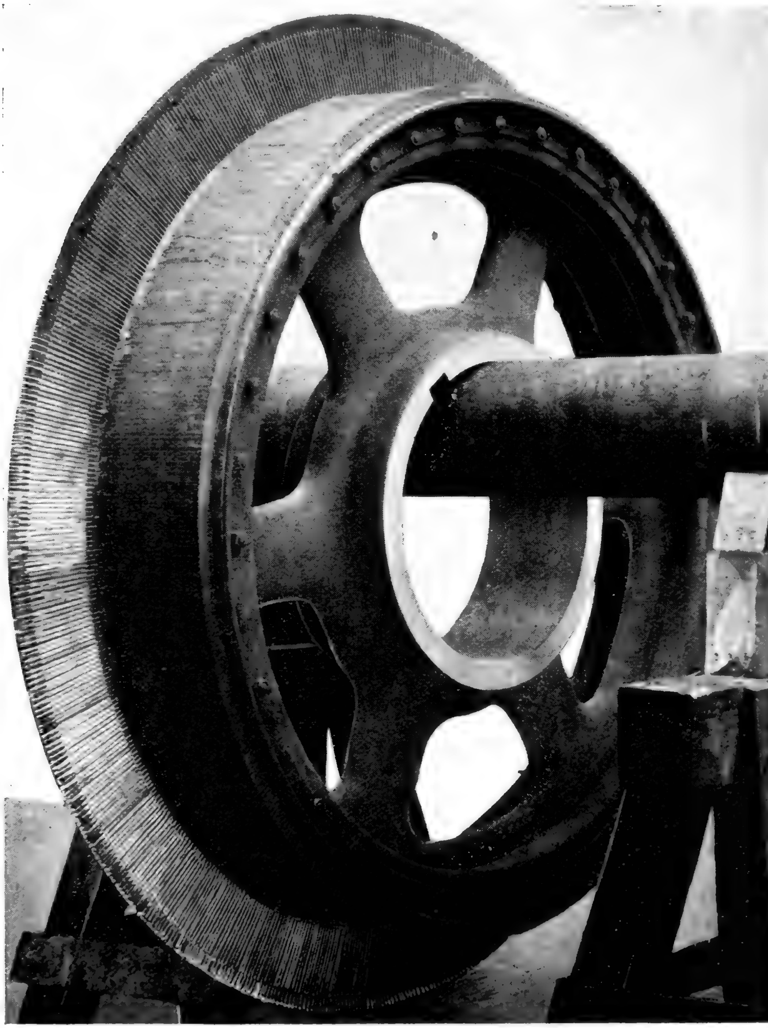


Fig. 137.—Large Finished Commutator. Dick, Kerr & Co.

which is frequently used in large commutators. A photograph of a commutator built on these lines is shown in Fig. 137. In connection with the mica V-rings, it may be noted that there is a difference between their arrangement in Figs. 135 and 136.

In Fig. 135 the mica V-ring is in one piece, fitting over the V of the metal end ring; whereas in Fig. 136 the mica V-ring is made up of two pieces, which wedge up together at the roots of the dovetail in the commutator segments, where a small recess is turned.

The latter practice is recently becoming customary with several makers, and it is stated that it gives more satisfactory results, and the insulating rings have better insulating properties.

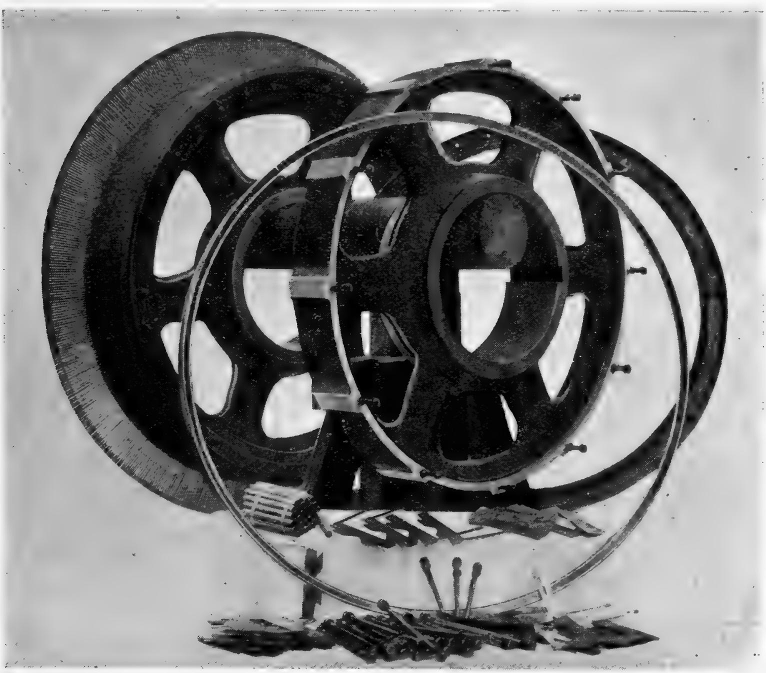


FIG. 138.—Component parts of large Commutator. Dick, Kerr & Co.

It is said that in some cases where the hitherto common method of Fig. 135 is employed, the mica ring gets strained at the corner of the V when subjected to the pressure during the tightening up of the commutator, and is liable to break in places at the corner of the dovetail. It is further maintained that it is not reasonable to expect such good insulation in a micanite ring with a small radius of curvature as may be obtained with two independent cones.

Fig. 138 shows a group of the component parts of a similar commutator. In these cases, where practicable, it is preferred to mount the commutator spider upon an extension of the armature spider, rather than upon the shaft.

It is sometimes customary to construct the end V clamping ring in several sections, each of which is separately bolted on to the spider, as this arrangement enables any single faulty bar to be repaired and replaced without disturbing the rest of the commutator. This is only to be recommended for large commutators, but even in these cases it is not now often used.

Fig. 139 illustrates a commutator of this type by Messrs Siemens & Halske.

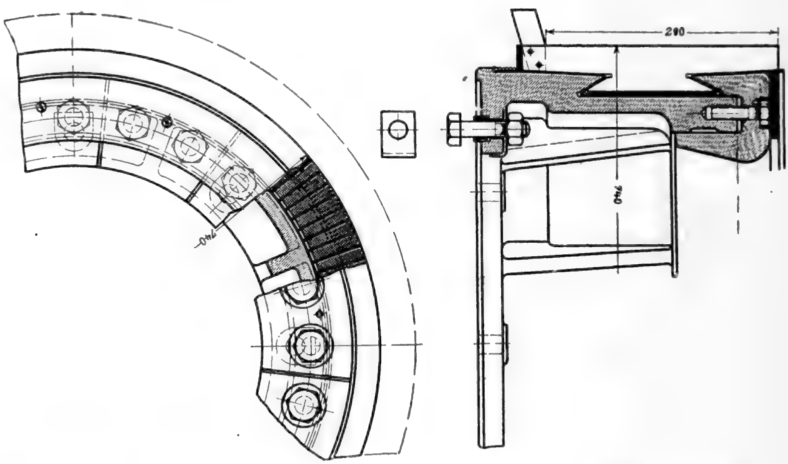


FIG. 139.—Commutator for 110 k.w. 500 volt. Dynamo. Siemens & Halske.

For small commutators the construction shown in Fig. 140 is suitable. This construction is arranged to provide for good ventilation on the inside of the commutator, and to this end the internal surface is left exposed and the end plates left as open as practicable.

In moderate and large-sized commutators it is standard practice to employ rolled or drawn copper for the segments, with a radial lug of copper strip fixed at the back end of each segment for connecting it on to the ends of the armature coils.

The lug is commonly fixed as shown in Fig. 141; the segment is drilled with three or more holes A, and one side milled away to a depth equal to the thickness of the strip, which is held on by rivets in the holes A and then brazed or sweated on.

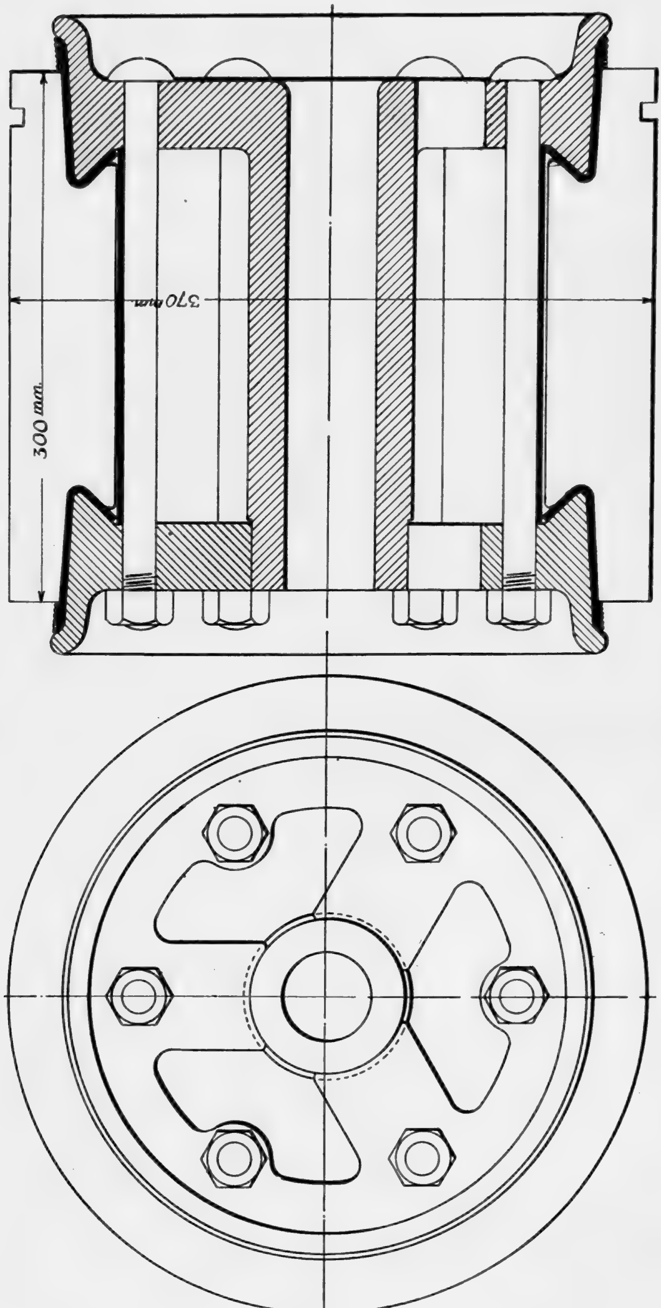


Fig. 140.—Small Ventilated Commutator.

In Fig. 141 the lug consists of two strips, one on the other, riveted together, which separate at their outer end and embrace the ends of the armature coils in the manner shown.

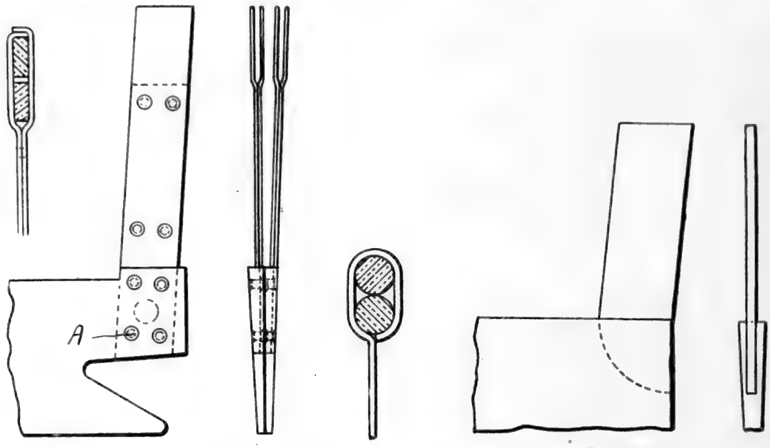


FIG. 141. FIG. 142. FIG. 143.

Methods of attaching Commutator Lugs and connecting to Armature Conductors.

If the lug is only a single strip of copper, it is brought round, as shown in Fig. 142.

Another method of fixing the lug to the segment is to mill out a groove at the end, into which the lug is sweated, as in Fig. 143. Fig. 144 shows a photograph of a commutator having these grooves. If the commutator diameter is nearly equal to the armature diameter, so that no lugs are necessary, the conductors, if of rectangular section, are brought out straight into the milled groove as shown in Fig. 145.

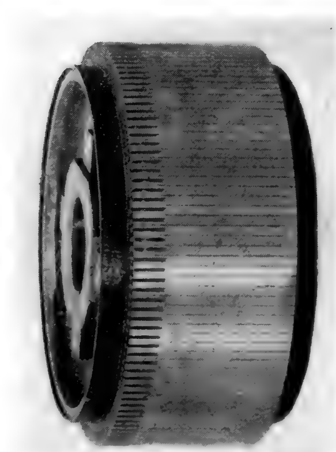


FIG. 144.—Alioth Co. Finished Commutator.

If the commutator is forged with the lug in one piece with the segment, the arrangement of Fig. 145 is commonly used.

Fig. 146 shows a common method for wire wound armatures.

Fig. 147 shows a method in which the lug is attached to the segment by screws; this method is not frequently employed.

In general, the breadth of the segment at the periphery of the commutator should not be, except in the case of very small motors, less than about 4 mm., but there is no reason why smaller thicknesses cannot be employed in certain cases. The factors which limit the thickness of the bar are the method of manufacturing the bars and the mode of attaching the lug, or the ends of the armature winding. In fact, a thickness down to less than 3 mm. may be quite practical, as is instanced by the following figures quoted by R. Livingstone:[1]—

0·14 in. (3·6 mm.) thickness in a commutator 30 in. (760 mm.) diam. × 9 in. (228 mm.) long.

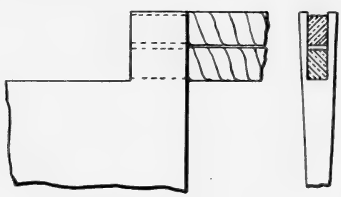


FIG. 145.

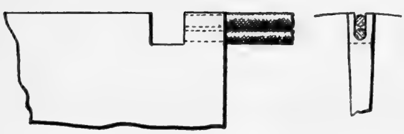


FIG. 146.

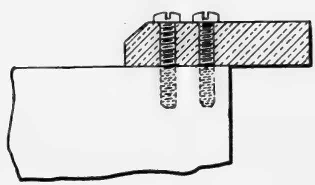


FIG. 147.

Methods of attaching Commutator Lugs and connecting to Armature Conductors.

0·125 in. (3·2 mm.) thickness in a commutator 19 in. (482 mm.) diam. × 10¼ in. (260 mm.) long.

0·105 in. (2·72 mm.) thickness in a commutator 15 in. (380 mm.) diam. × 5½ in. (140 mm.) long.

0·098 in. (2·5 mm.) thickness in a commutator 8 in. (203 mm.) diam. × 3 in. (76 mm.) long.

As further examples, the following are four cases from the writers' designs :—

3·1 mm.	thickness	of segment	185 mm.	diam.,	30 mm.	long.
2·2 ,,	,,	,,	254	,,	65	,,
3·0 ,,	,,	,,	200	,,	50	,,
3·0 ,,	,,	,,	280	,,	70	,,

[1] Mechanical Design of Commutators for Direct Current Generators, *Electrician*, vol. lvii. pp. 171–172, May 18, 1906.

Commutators for High Speeds.

In ordinary dynamos the linear speed at the periphery of the commutator does not exceed 20 metres per second, and is preferably less than 14 metres per second; but with high speed dynamos, such as are used for direct coupling to steam turbines, the peripheral speed may necessarily be as high as 35 or 40 metres per second.

To keep down the peripheral speed it is necessary to employ small diameters for commutators, but to get a sufficient number of segments in the periphery and also to obtain a well-proportioned commutator with sufficient collecting and radiating surface, such diameters have to be employed, with high speed dynamos, as lead to peripheral speeds as high as those just mentioned.

The characteristics of high speed commutators are the small diameters and great axial lengths. The high centrifugal forces on the segments, incident to the high speed, render inadequate the ordinary constructions as outlined in the previous part of this chapter. Consequently, special constructions have been necessary, of which that shown in Fig. 148 is typical, and the general lines on which this is built are now becoming standard for high speeds.

Instead of the ordinary V clamping rings, the segments are retained by stout steel rings shrunk on the outside of the commutator.

The process of building such a commutator is as follows:—The segments are first assembled with the mica pieces between them, in the manner described earlier in this chapter, and held together with a few turns of wire or rope. The steel rings are then shrunk on over the segments, with a layer of mica to insulate them from the segments. The assembly is now put on a boring mill and the interior machined, the ends being bored taper, as seen in Fig. 148.

The commutator shown is built up on a sleeve; but it is common practice, especially with smaller commutators, to bed the commutator direct on the shaft, a taper being turned on the shaft at the end nearest the armature, to fit the taper to which the interior of the commutator is bored. In the latter case the shaft, or, in Fig. 148, the metal sleeve, is covered with a sleeve of mica.

The commutator is held up against the taper at the armature end by means of a double taper collar fitting the taper bore on the inside of the commutator at the other end. These collars are

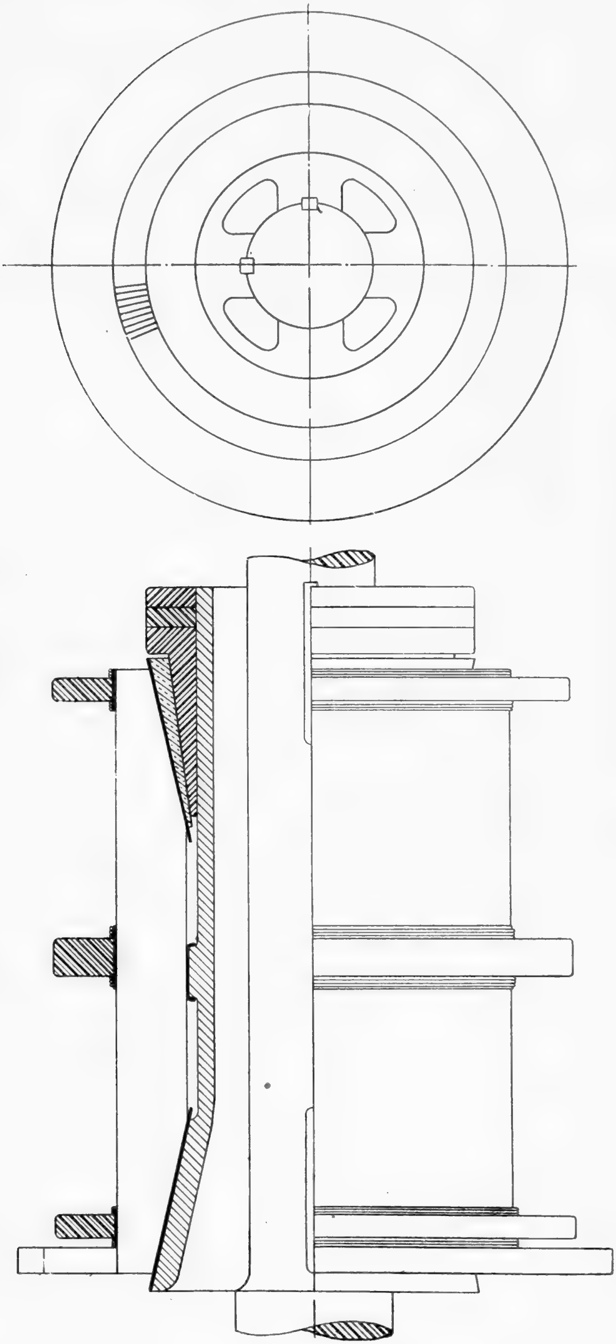


FIG. 148.—Typical Commutator used for Turbo-Dynamos.

tightened up by means of a pair of lock-nuts on the sleeve, or on the shaft direct.

After the commutator has been assembled in this way, it is ready for machining on the outside; the steel rings as well as the segments being turned all over. For high speed commutators, the sections for the segments shown in Figs. 149 and 150 have been employed, with a view to further security of the segments against the radial forces.

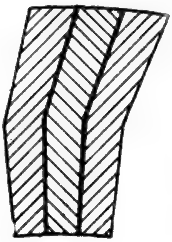


FIG. 149.

FIG. 150.

Types of Segments used for High-speed Commutators.

The construction shown in Fig. 149 is used by the Brush Electric Engineering Company, and the construction shown in Fig. 150 is the invention of James Burke. It will be seen that the adjacent segments lock on each other along their whole length: the segments in each case would be cut to the required lengths from bars rolled or drawn to the required section.

Commutator bushes or spiders are generally of cast iron, as are also the V clamping rings, except in large commutators, where steel is usually employed.

In very small commutators the bush and end V-rings are often of brass, the end ring being tightened on to the brush by a screwed collar, instead of being drawn up by bolts as in larger sizes.

CHAPTER VIII

CONTINUOUS-CURRENT ARMATURE WINDING SYSTEMS

For all except comparatively small designs, a type of armature winding known as a "Multiple-Circuit Winding" is almost exclusively employed for continuous-current machines. This winding owes its name to the circumstance that there are as many conducting paths (circuits) for the current to traverse in passing through the armature from the negative to the positive brushes, as there are poles in the machine. Multiple-circuit windings may either be "simplex" or they may be "multiplex" (*i.e.* duplex, triplex, etc.). Multiple-circuit *multiplex* windings are, however so little employed that it is not convenient to always state explicitly that a certain armature has a multiple-circuit *simplex* winding. It is, on the contrary, customary and practicable to simply state that it has a multiple-circuit winding, and to realise that, if it had a duplex or triplex winding, it would be explicitly stated that it had a multiple-circuit *duplex* winding or a multiple-circuit *triplex* winding, as the case might be. So let us, for a considerable part of this chapter, completely dismiss from our minds the knowledge of the existence of any type of windings other than multiple-circuit *simplex* windings, and let us refer to these as "multiple-circuit" windings.*

Let us, furthermore, begin by limiting our thoughts to windings with but one turn between adjacent commutator segments. Such an elementary turn, with its corresponding commutator segments, is illustrated diagrammatically in Fig. 151. Suppose that this is a turn of a 4-pole winding with 96 segments; then there will be 96 turns, and hence $2\times 96=192$ face conductors. If, as in Fig. 152, we denote the left-hand conductor by 1, then the number of the corresponding right-hand conductor of this single turn will be found by adding

$$\left(\frac{192}{4}\pm 1\right)=47 \text{ or } 49 \text{ to } 1.$$

* A chart showing the derivation of the types of continuous-current windings is given in Plate XIV.

Hence, as right-hand conductor of this turn, we should choose

$$1+47=48, \text{ or } 1+49=50.$$

Let us choose the latter, and designate the right-hand conductor as number 50, as shown in Fig. 152.

We shall make a practice of writing the number of each conductor in some such relative position as that shown in Fig. 152.

In Fig. 153 we have thus drawn and numbered conductors 1, 2, 49, and 50. Let us furthermore introduce into Figs. 152 and 153 the additional convention of representing all even-numbered

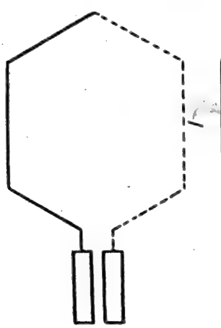


Fig. 151.

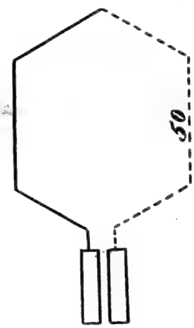


Fig. 152.

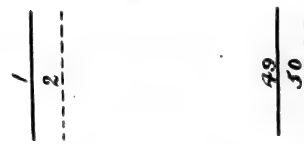


Fig. 153.

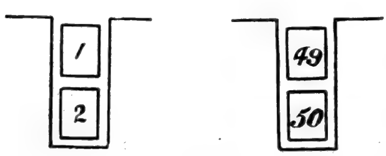


Fig. 154.

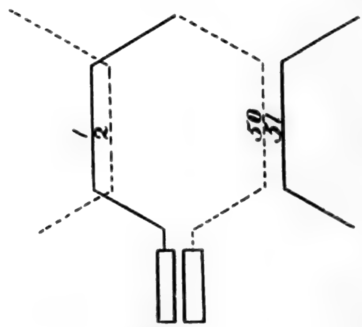


Fig. 155.

Conventional Elements of Winding Diagram.

conductors by dotted lines. If this is a winding with two conductors per slot, and if 1 and 2 are the top and bottom conductors in one slot, then a moment's reflection will show that 49 and 50 are top and bottom conductors respectively of another slot, as indicated in Fig. 154.

We thus have the further rule which we must always keep distinctly in mind—that top conductors are denoted by odd, and bottom conductors by even, numbers. Also, the top conductors are represented by full lines and the bottom conductors by dotted lines.

It might be supposed that as 1 and 50 constitute the two sides of one turn, 2 and 51 would constitute the two sides of another turn. This is not the case. Conductor No. 2 is connected to another conductor *to the left*, and not as yet shown in the diagrams; while conductor No. 51 is connected to a conductor *to the right*, and not as yet shown in the diagrams. In fact, the state of affairs, so far disclosed by our investigation, is that illustrated in Fig. 155.

We thus see that all top conductors (*i.e.* all odd-numbered conductors) are connected over to the right, and all bottom

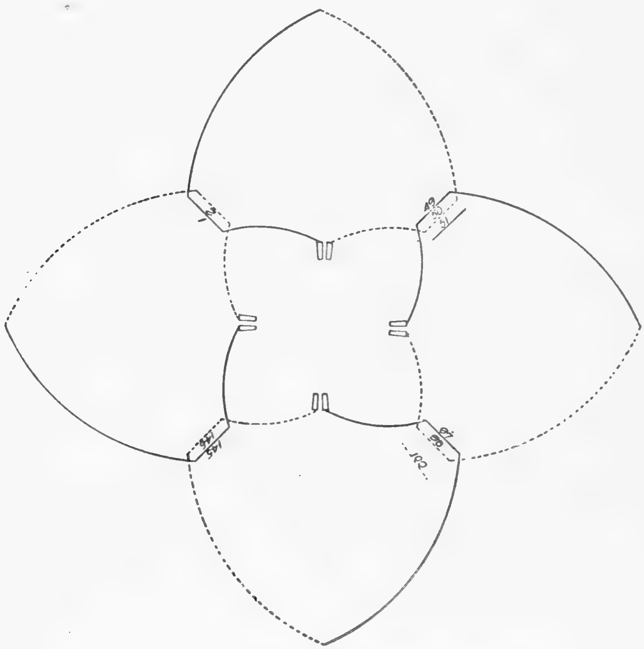


Fig. 156.—Element of Winding Diagram.

conductors (*i.e.* all even-numbered conductors) are connected over to the left. Just as conductor No. 1 is connected to conductor No. (1+49), *i.e.* to conductor No. 50, so conductor No. 51 is connected to conductor No. (51+49), *i.e.* to conductor No. 100 (see Fig. 157). Similarly, conductor No. 49 is connected to conductor No. (49+49), *i.e.* to conductor No. 98 (see Fig. 156); and conductor No. 97 to conductor No. (97+49), *i.e.* to conductor No. 146; and conductor No. 145 to conductor No. (145+49), *i.e.* to conductor No. 194.

But, it will be asked, "Where is conductor No. 194? There are only 192 conductors." This, of course, is true; but as there is neither end nor beginning to a circle, so also, in the case of a multiple-circuit armature winding, which is arranged on the periphery of a circle, we may take conductor No. 194 as having its equivalent in conductor No. (194 – 192), *i.e.* in conductor No. 2. Thus, finally, we have found out that which we wanted to know a few paragraphs back, *i.e.* the number of the conductor to which conductor No. 2 is connected. The quantity, 49, which we add in

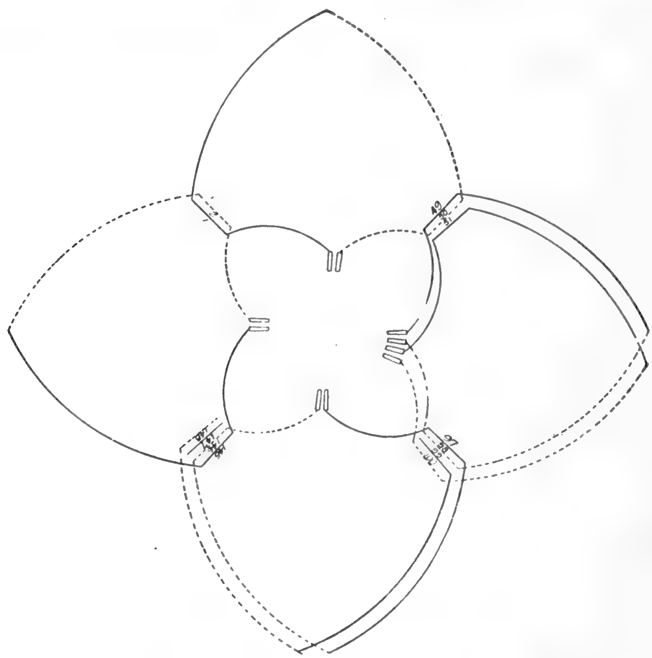


Fig. 157.—Element of Armature Winding Diagram.

each case in the process of connecting up, is called the "winding pitch," or, briefly, the "pitch," and is denoted by y. We call the two ends of the armature the "front" (or commutator) end, and the "back" end. The quantity, 49, is the "back-end pitch," *i.e.* it is the number to be added to any conductor in order to find out the conductor to which, at the back end, it is connected. For the present it should merely be noted that, at the "front" end, both ends of any turn are carried to commutator segments.

It is very convenient to diagrammatically represent windings as shown in Fig. 156. For the time being, however, the only conductors shown and numbered are the ten conductors 1, 2, 49, 50, 97, 98, 145, 146, as also 51 and 100, as these are the only ones to which allusion has as yet been made.

In such a diagram, it has become conventional practice to let the inside of the diagram represent the commutator end, and the outside the back end. The face conductors are diagrammatically represented by the radial lines, and the end connections by other lines, the inclination or curvature of which is so chosen as to give a maximum of distinctness to the diagram.

The final practice of diagrammatically representing commutator segments in winding diagrams, will be shown in a subsequent figure. In the case of Fig. 156, the eight little rectangles toward

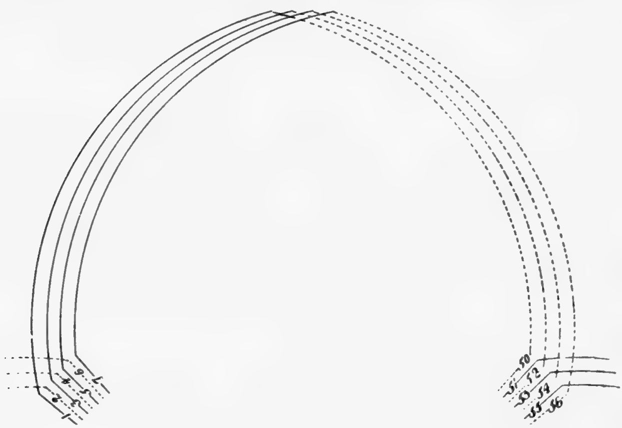


FIG. 158.—Back-end connections.

the centre of the figure will be readily recognised as intended to represent the commutator segments.

The only irregular feature of the diagram of Fig. 156 relates to conductors Nos. 51 and 100. Conductor No. 100 constitutes the right-hand side of the turn of which conductor No. 51 is the left-hand member. Similarly conductor No. 53 is connected over the back end to conductor No. (53+49), *i.e.* to conductor No. 102.

Thus also we have :—

Conductor No. 1 is connected at the back end to conductor No. 50.
" 3 " " " 52.
" 5 " " " 54.

These steps are taken in Figs. 157 and 158, and were we to carry this out all the way round the circumference, we should obtain a diagram of which a portion is shown in Fig. 158.

In Fig. 159 we have added the two front ends of each turn carrying them to independent commutator segments. But this gives us 192 segments, and we have stated that our winding, which comprises 192 conductors, has *one turn*, i.e. *two conductors*,

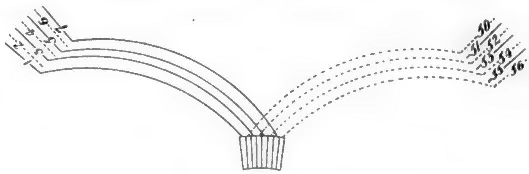


FIG. 159.—Front-end connections.

per commutator segment, and hence only 96 segments. Thus we must merge every *pair of adjacent* segments into a *single* segment, taking care, however, to take such pairs as are not the neighbouring terminals of a single turn, otherwise we should simply obtain a set of 96 short-circuited turns.

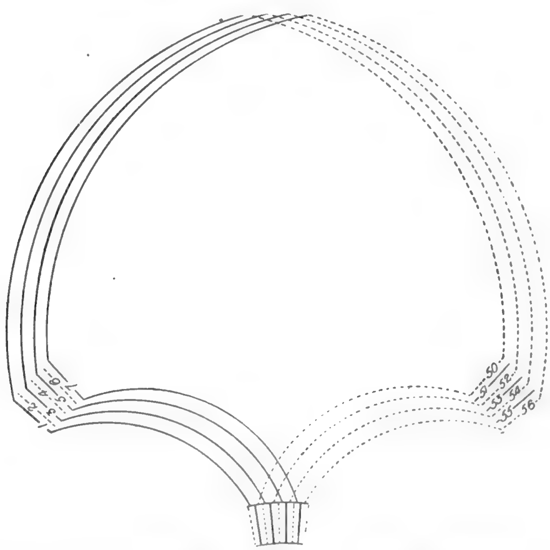


FIG. 160.—Elements of Armature Winding Diagram.

With this precaution we shall obtain the diagram of Fig. 160, in which the dotted radial lines on the commutator are the lines which in Fig. 159 divided the now merged segments. In Fig. 161 these dotted lines are suppressed. This is still not quite in the conventional form; there is still required the further minor modification introduced in the complete diagram of Fig. 162, and consisting in connecting the commutator segments to the winding by means of short radial lines which have their equivalent in practice in the leads from the winding to the commutator, although, of course, *some* armatures are actually constructed in accordance with the method indicated in Fig. 160—*i.e.* the ends of the turns are carried directly to the segments. More often, however, the method actually adopted corresponds with the diagram of Fig. 162, in which it is indicated that additional strips are introduced, connecting from the winding to the commutator.

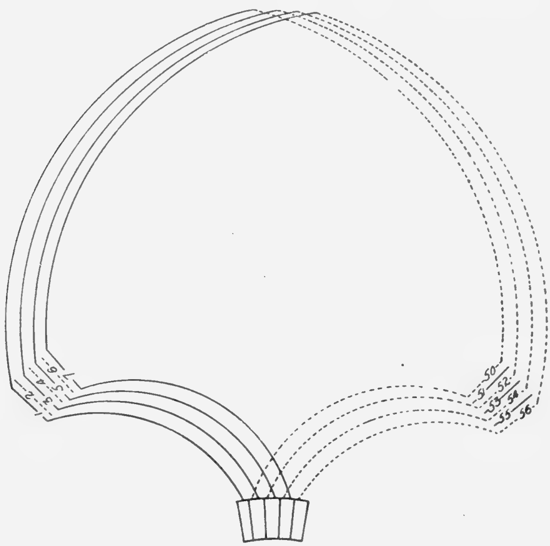


FIG. 161.—Elements of Armature Winding Diagram

In Fig. 162 we have now drawn the complete winding diagram for the armature, which would be arrived at by simply continuing Fig. 161. To clearly indicate the front and back winding pitches, the turn comprising conductors 1 and 50 has been thickened in.

We see that the "front end pitch" is equal to

$$50 - 3 = 47,$$

i.e. at the front end, conductor No. 50 is connected to conductor No. 3. As the connection at the front end is carried out in the opposite direction, *i.e.* counter-clockwise, we may say that the front end pitch is in this case negative, *i.e.* it is equal to -47.

It is customary to denote the winding pitch by y, and to distinguish between the "back end" and the "front end" pitches by designating them as

$$yb = (\text{"back end pitch"})$$

and

$$yf = (\text{"front end pitch"}).$$

In the winding of Fig. 162 we have

$$yb = 49$$
$$yf = 47.$$

We may denote the mean pitch as y—*i.e.*

$$y = \frac{yb + yf}{2} = \frac{49 + 47}{2} = 48.$$

Thus y (*i.e.* the *mean* pitch) is equal to the total number of face conductors divided by the number of poles. In this case

$$y = \frac{192}{4} = 48.$$

The precise values of the front and back pitches are determined by taking the one greater by 1 than the value of the mean pitch, and the other less by 1 than that value; thus in the present case we have

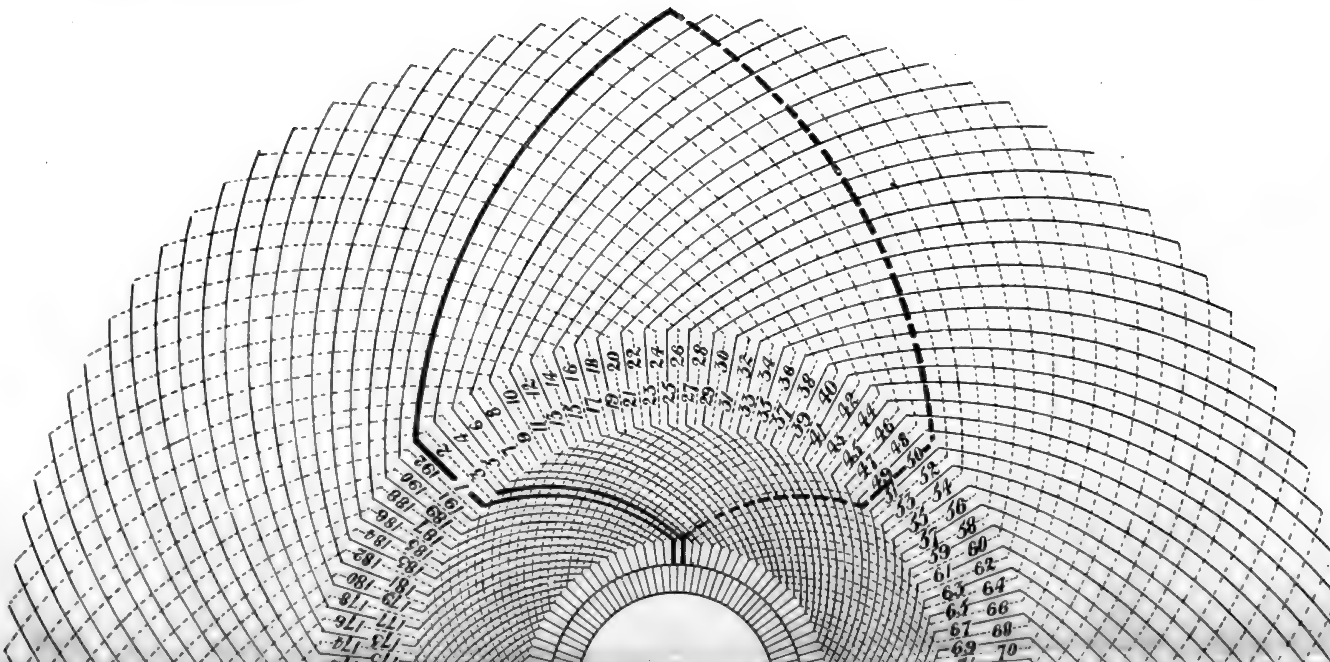
$$yb = y + 1 = 48 + 1 = 49$$
$$yf = y - 1 = 48 - 1 = 47.$$

Let us employ this same number of face conductors, *i.e.* 192, but connect them up into a 6-pole winding.

$$y = \frac{192}{6} = 32$$
$$yb = 32 + 1 = 33;\ yf = 32 - 1 = 31.$$

The winding diagram is given in Fig. 163.

The present treatise deals with questions relating to the *construction* of armatures, and for this reason questions of electro-magnetic design are not entered upon, or, at the most, are kept in the background. It is necessary to allude to this plan in the present chapter, since otherwise the method of dealing with armature windings would not be clearly appreciated. In carrying out the design of the winding in the draughting office and in the construction work in the shop, a considerable degree of familiarity with the electro-magnetic properties of windings is highly desirable. It is, however, neither necessary nor desirable to deal



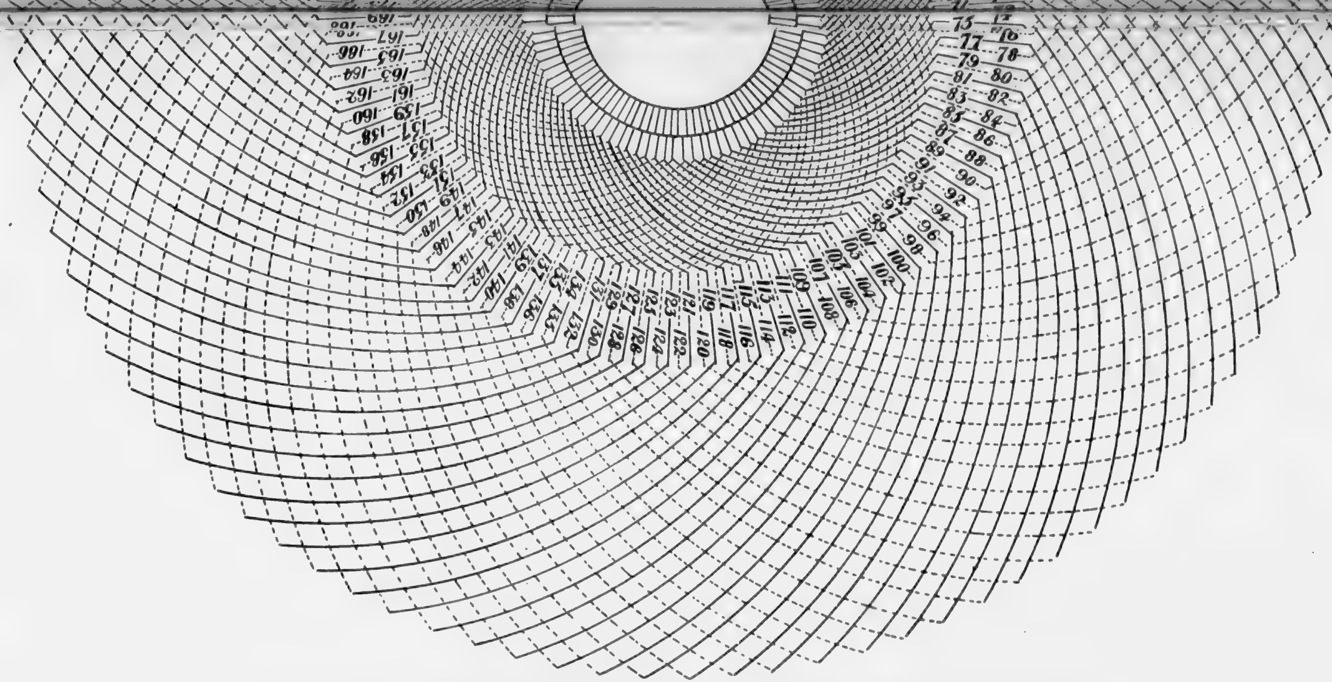
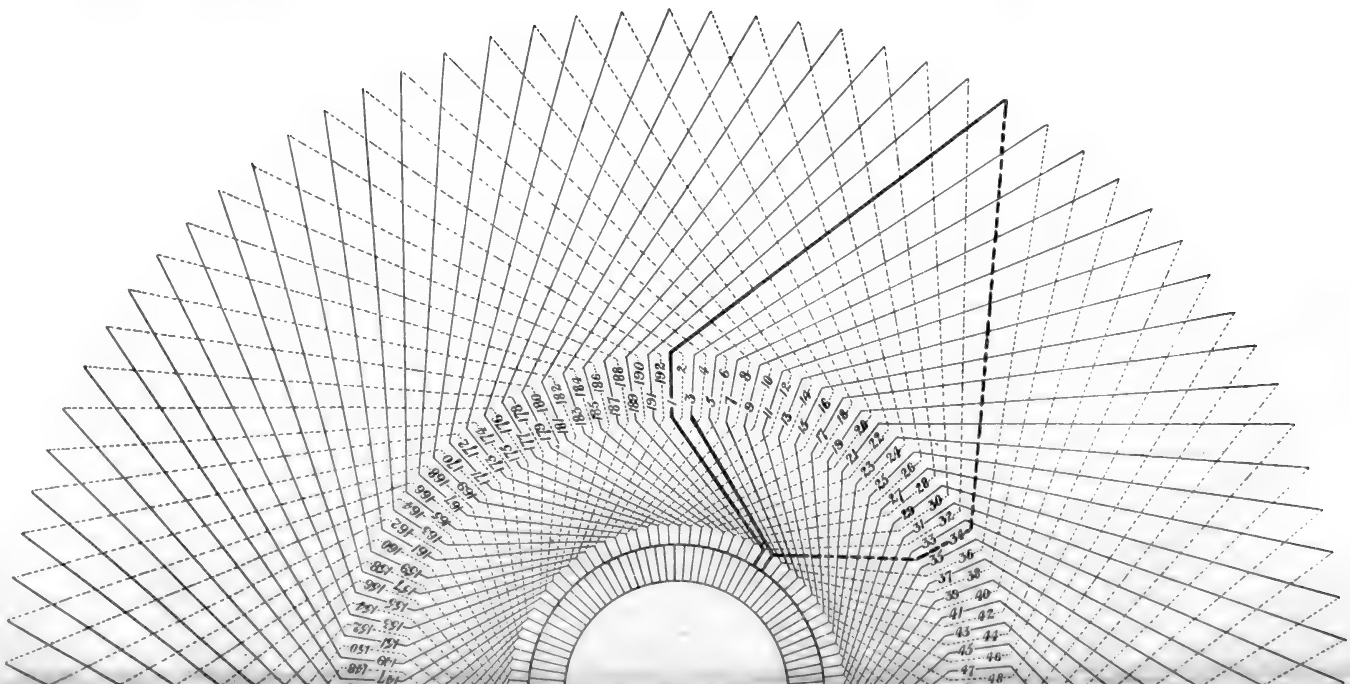


FIG. 162.—Winding Diagram for Four-pole Armature with 192 Conductors. $yb=49$; $yf=47$.



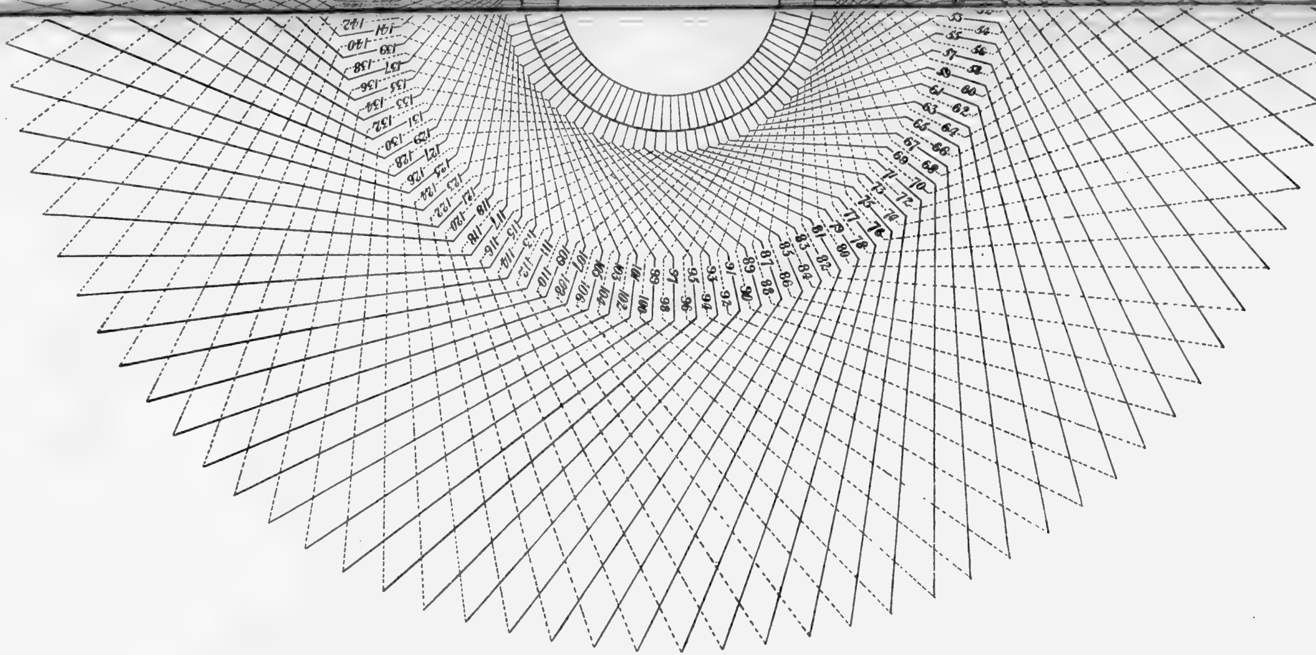
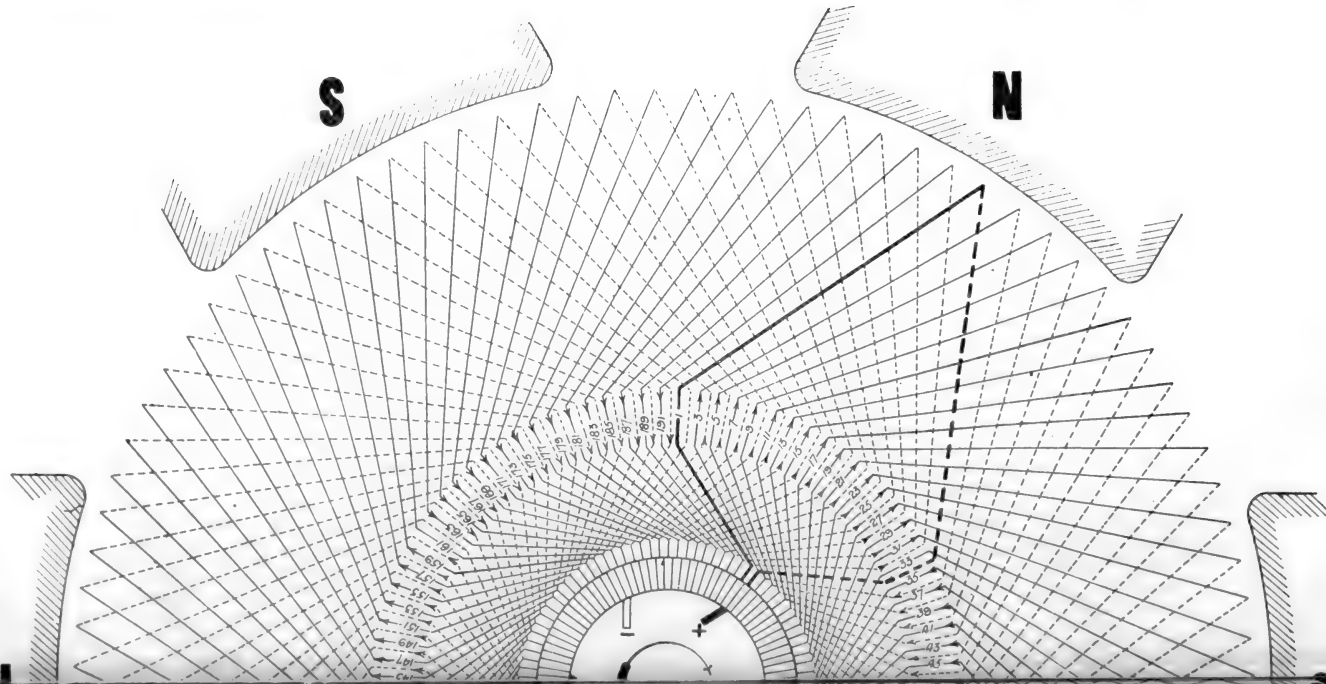


FIG. 163.—Winding Diagram for Six-pole Armature with 192 Conductors. $yf=31$; $yb=33$.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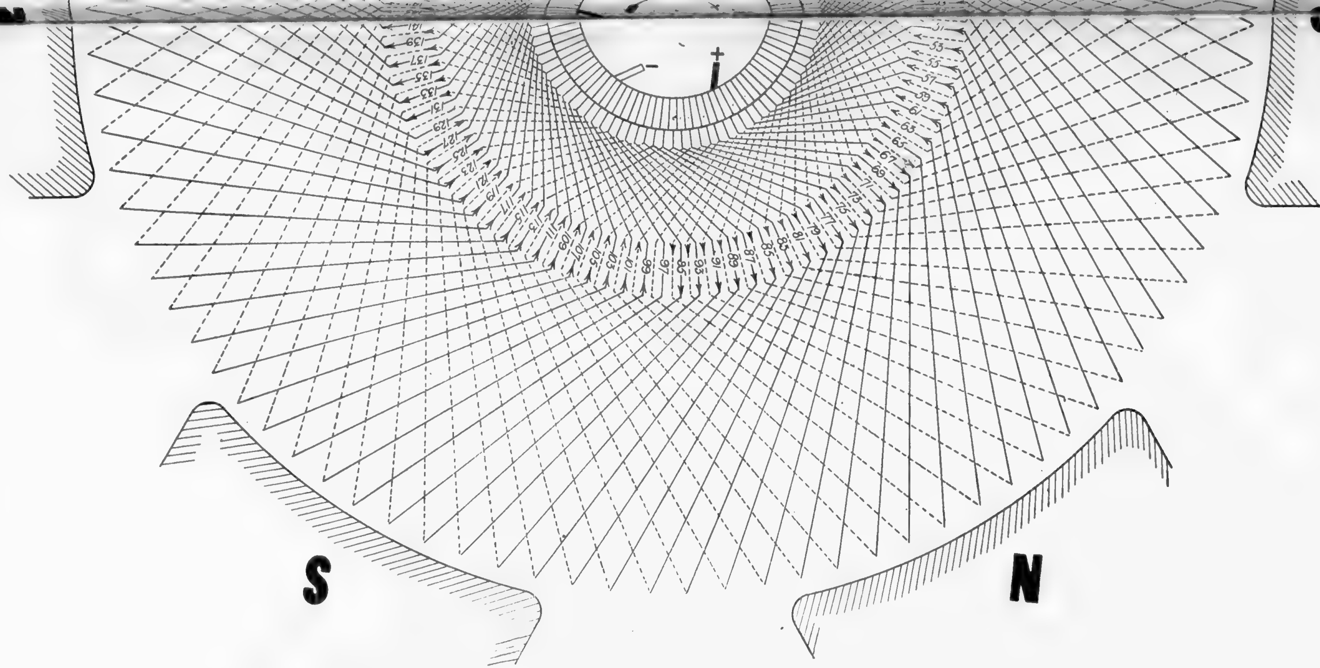


Fig. 164.—Winding Diagram for Six-pole Armature with 192 Conductors (six-circuit).

with the subject on quite the same lines as would be suitable in a treatise intended to be employed exclusively by those entrusted with the task of the pre-calculation of the electro-magnetic design. Those so engaged can profitably familiarise themselves with the aspects of the subject on which emphasis is laid in this treatise; they should, however, also master the further aspects of the subject as set forth in treatises dealing more especially with electro-magnetic design.[1]

It is believed that, in view of the above explanation, the less frequent allusion to the question of current distribution in the windings will be appreciated. Briefly, it may be stated that where desirable to indicate the paths of the current, the direction *through the winding* from negative to positive brushes is indicated by arrow-heads affixed to the radial lines representing face conductors. As the current changes its direction as the conductors pass under each successive pole, it is only practicable in a single diagram to indicate the direction at some particular instant. The rule for ascertaining the direction of the current for the case of a machine when employed as a generator,[2] is as follows:

When a conductor passes under a *north pole* in a *clockwise* direction from the observer's standpoint, the electro-motive force

[1] Amongst these treatises, the writer naturally prefers those in which the nomenclature here employed has been adopted. The most extensive treatise is *Armature Windings*, Parshall & Hobart (New York, D. van Nostrand Co., 1895).

The subject is much more briefly dealt with in *Electric Machine Design*, Parshall & Hobart (London, offices of *Engineering*, 1906); *Electric Motors*, H. M. Hobart (London, Whittaker & Co., 1904); and *Elementary Principles of Continuous-Current Dynamo Design*, H. M. Hobart (London, Whittaker & Co., 1906).

Dr Thompson and Prof. Arnold have handled the subject most ably; the nomenclature they employ is, however, considerably at variance with that in the other treatises and in the present volume. W. Cramp, however, in a most interesting little volume, *Armature Windings of the Closed Circuit Type* (London, Biggs & Co., 1906), has employed substantially the nomenclature adopted in the present treatise.

[2] It is almost superfluous to state that when the machine is run as a motor, the current will flow in just the opposite direction for a given direction of motion of the conductor under a pole of a given polarity. The electro-motive force induced in a conductor by its passage through the magnetic field, is the same in both cases; but in the case of a generator, the current flows under the influence and in the direction of this induced electro-motive force, whereas in the case of a motor, it flows in the direction and under the influence of an external electro-motive force which is greater than the induced (and, in this case, counter) electro-motive force in *opposition* to which it flows.

thereby induced in the conductor, and the current flowing when the circuit is closed, will be directed *away from* the observer.

In the present chapter the arrow-heads will always indicate the direction of the *induced* electro-motive force, *i.e.* the direction of both electro-motive force and current for the case of a dynamo.

The diagram in Fig. 164 differs from that in Fig. 163 only in the addition of (1) the brushes as there shown diagrammatically inside the circle representing the commutator surface, (2) arrow-heads showing the direction of the current, and (3) diagrammatic representations of the pole faces. These latter are sketched at the very outer edge of the diagram in order not to confuse the rest of the diagram by additional lines. It will be seen that the typical turn (represented by heavy lines), consisting of conductors 1 and 34, as well as five other equally spaced turns (33–66, 65–98, 97–130, 129–162, and 161–2), is not provided with arrow-heads. This is because, at the instant considered, these six turns are passing through the position of short circuit under the six brushes, which are shown resting upon the twelve commutator segments connected to the twelve ends of these six turns. The direction of motion is clockwise, as shown by the large arrow at the centre of the diagram.

Increased familiarity with armature windings may be obtained by constructing so-called "developed" diagrams. A recent suggestion for the arrangement of "developed" diagrams is that of Stembridge.[1] In Fig. 165 is shown, arranged in accordance with this method, a diagram of a 6-circuit winding with 60 conductors. The winding pitches are given by the formula

$$y=\frac{60}{6}\pm 1,$$

whence

$$yf=9$$
$$yb=11.$$

In a diagram drawn according to the Stembridge method, the two ends of the armature are shown exactly the same size with the end connections precisely as they might appear on the actual armature. The cylindrical surface is shown "developed" or rolled out flat on the paper, between the two end drawings, and the conductors are shown jointed to their end connections by thin lines, which, of course, unlike the other lines, do not represent

[1] "A Simple Method of representing Armature Windings," E. K. Stembridge, *Electrical World and Engineer*, vol. xlvii. p. 265, 3rd February 1906.

any part of the winding on the actual armature. The advantages claimed for this method of representing windings relate to its simplicity, the readiness with which it may be drawn to scale, and to the fact that the end drawings appear precisely as the ends of the actual armature. We have further added, in Fig. 165, the six poles of the machine in their correct positions relative to

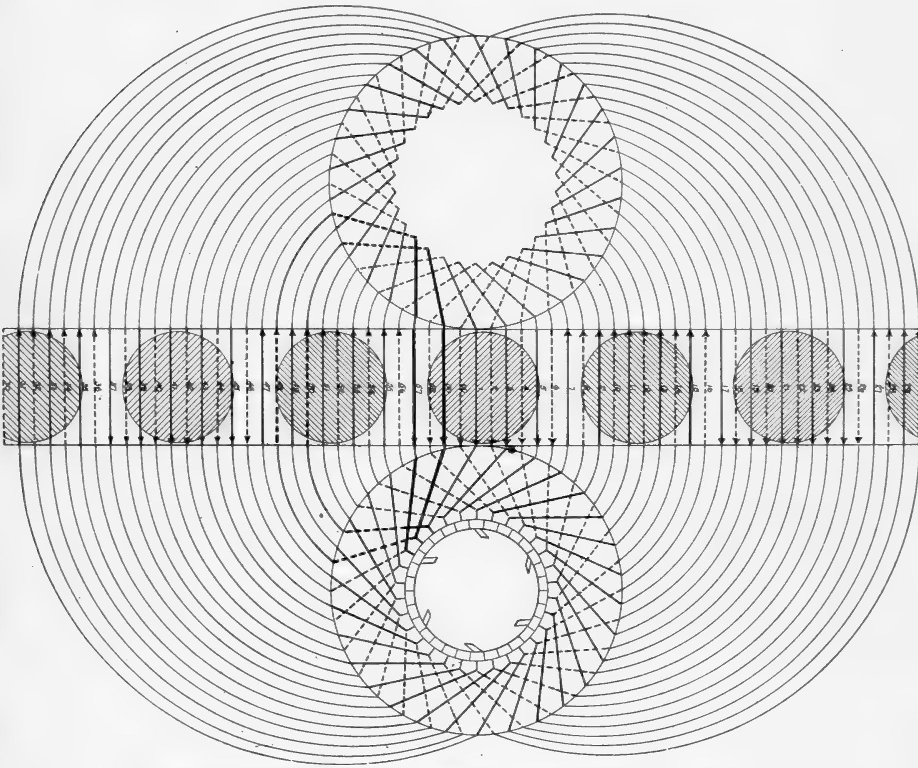


FIG. 165.—Developed Winding Diagram for 6-circuit 6-pole Armature, 60 Conductors. $yf=9$, $yb=11$.

one another, and have shaded these in two directions to represent respectively the N poles and the S poles. As will be seen, this diagram permits of the poles being drawn in a true position with respect to the armature conductors, and the shaded areas may be regarded as developed surfaces of the pole faces.

The above points render this method of drawing advantageous for those whose knowledge of armature windings is very elementary; but to one accustomed to winding diagrams, the ordinary diagrams, as in Figs. 162, 163, and 164, present the conditions sufficiently closely, and may be more quickly drawn. Moreover, the drawing of the connecting lines between the conductors and ends in Fig. 165 is a rather long process, and these lines have no counterpart on the actual armature.

Two-circuit Windings.

It will have been noticed that in multiple-circuit windings, successive conductors (following the winding connections) lie

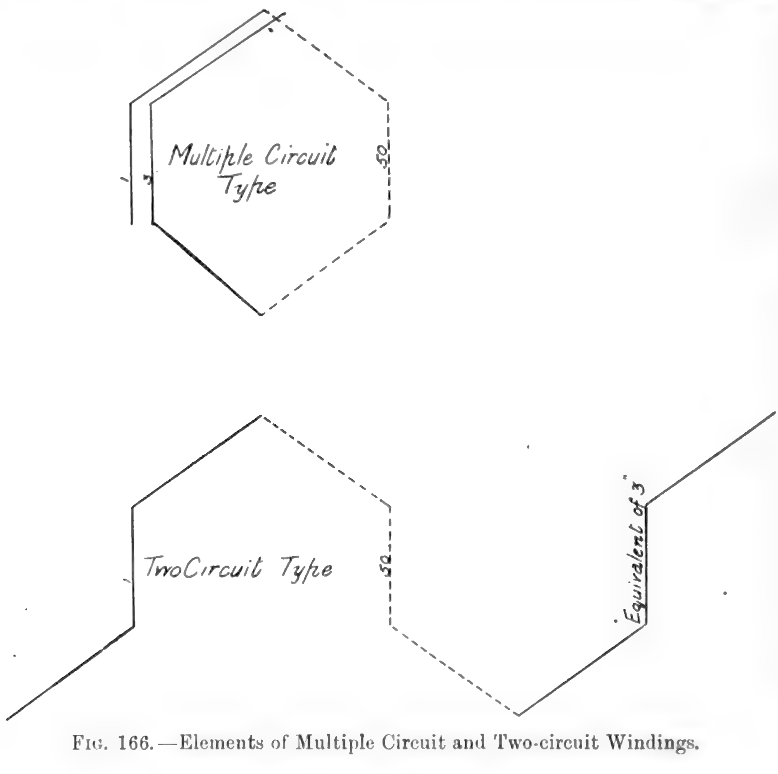


Fig. 166.—Elements of Multiple Circuit and Two-circuit Windings.

under poles of opposite polarity. Thus in the first winding considered (Figs. 151 to 162), the connection was from conductor No. 1 over the back end to No. 50, then over the front end to No. 3. If conductor No. 1 lies under a north pole, conductor No. 50 will lie under a south pole, conductor No. 3 under a north pole, etc. The important requirement is that each successive conductor shall lie under a pole of opposite polarity. This, it is evident, could be accomplished by the arrangement shown in the lower half of Fig. 166, just as well as by the arrangement shown above it. The former plan is employed in the so-called two-circuit windings, the latter in the multiple-circuit windings. Fundamentally, therefore, the windings may be identified by these characteristics—namely (at any rate, in the case of windings with one turn per segment), as will be fairly readily seen from an inspection of an armature, that the connections at the front and back ends of a multiple-circuit winding are in the same direction when any particular conductor is considered, as seen in the left hand diagram of Fig. 167; and in opposite directions in the case of two-circuit windings, as seen in the right hand diagram of Fig. 167. The conductors designated respectively 3 and "equivalent of 3" in Fig. 166 are evidently at all times situated in fields of polarity opposite to that of the fields in which conductor No. 50 may be situated.

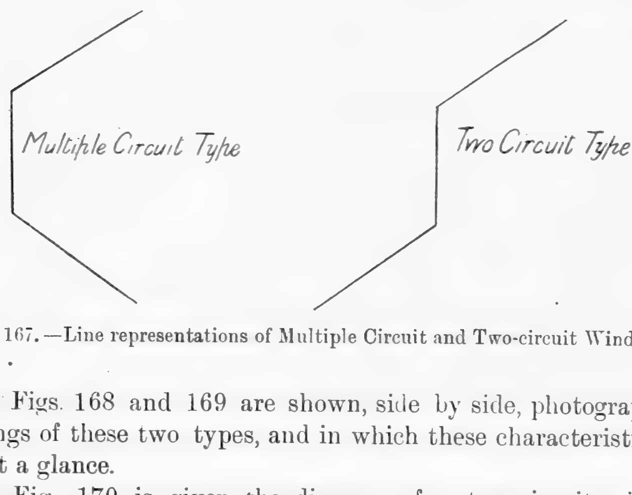


FIG. 167.—Line representations of Multiple Circuit and Two-circuit Windings.

In Figs. 168 and 169 are shown, side by side, photographs of windings of these two types, and in which these characteristics are seen at a glance.

In Fig. 170 is given the diagram of a two-circuit winding, developed by the method which we applied in Fig. 165 to a multiple-circuit winding.

It would be out of place in the present treatise to enter upon the theory of these two types of winding, as this is a subject which can only concern those individuals whose duty it is to carry out the electro-magnetic pre-calculations. Suffice it to point out here, that for a given number of face conductors and poles, a given magnetic flux from each pole, and a given speed, a multiple-circuit armature will have a lower voltage at the commutator than will a two-circuit winding. If it is a 4-pole machine, the multiple-circuit winding will have $\frac{2}{4}$, *i.e.* $\frac{1}{2}$ the voltage; if a 6-pole machine, $\frac{2}{6}$, *i.e.* $\frac{1}{3}$ the voltage, etc. But it will make up in current capacity that which it loses in pressure. Thus, suppose that two 6-pole armatures have the same number and size of conductors, and that the magnetic flux and the speed are the same in both cases: suppose the multiple-circuit winding, for a given heating, gives 600 amperes at 200 volts, then the two-circuit winding will give 200 amperes at 600 volts.

In everything that has been said, a two-circuit *simplex* winding has been assumed. There is, however, another large class of

Fig. 168.—Completed Lap Wound (Multiple-circuit) Armature.

two-circuit windings, which may be designated two-circuit *multiplex* windings. Thus we may have two-circuit duplex, two-circuit triplex windings, etc.; but these are not often employed, and unless expressly stated to the contrary, it may be understood that a two-circuit simplex winding is meant.

Multiple-circuit windings are sometimes called "lap" windings, and two-circuit windings are sometimes called "wave" windings. These two names have been suggested by the characteristics illustrated in Fig. 166. "Wave" windings (*i.e.* "two-circuit" windings), are often employed in machines of small capacity, and are also useful for intermediate capacities where the speed is low. They are characterised by having two circuits through the armature from positive to negative brushes, no matter how many poles there are; each of the two circuits carries one-half of the total current. The "lap" (*i.e.* "multiple-circuit") winding is more suitable for large machines, and is also required in machines of intermediate capacity where the speed is high. It is characterised by having as many circuits through the armature from positive to negative brushes, as the machine has poles, the current, of course, dividing equally amongst all

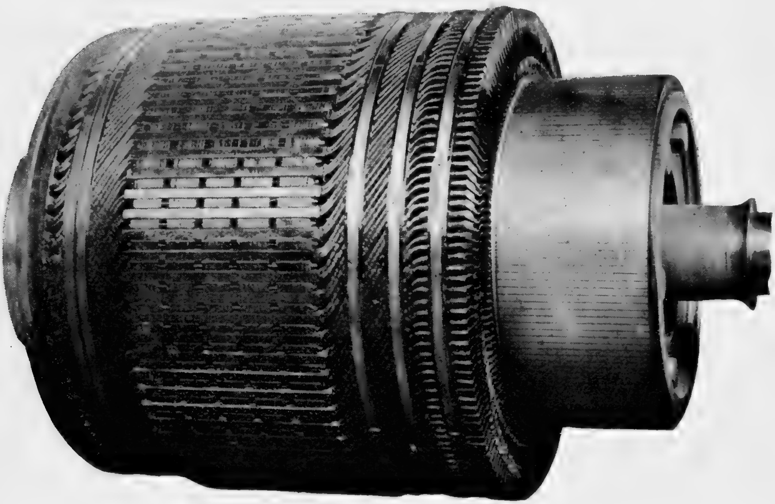


FIG. 169.—Completed Wave-wound Two-circuit) Armature.

these parallel circuits. Thus in a 1600-ampere 16-pole machine with a multiple-circuit winding, each circuit carries $\left(\frac{1600}{16}=\right)$ 100 amperes.

Thus, instead of comparing, as in a preceding paragraph, two armatures with the same number of conductors connected respectively as two-circuit and as multiple-circuit windings, we may also instructively compare two armatures for the same current and voltage, but wound respectively with these two types of winding. If the machine has four poles, then such a comparative study will show that the two-circuit winding has half as many conductors, and that each conductor is of twice the section, since it must carry half the total current; whereas each conductor of the multiple-circuit winding will only have to carry one-fourth of the total current.

If the comparison is for a 6-pole armature, the two-circuit winding will have but one-third as many conductors, and each conductor will have three times the section It is thought that these brief statements may be useful as illustrating the general

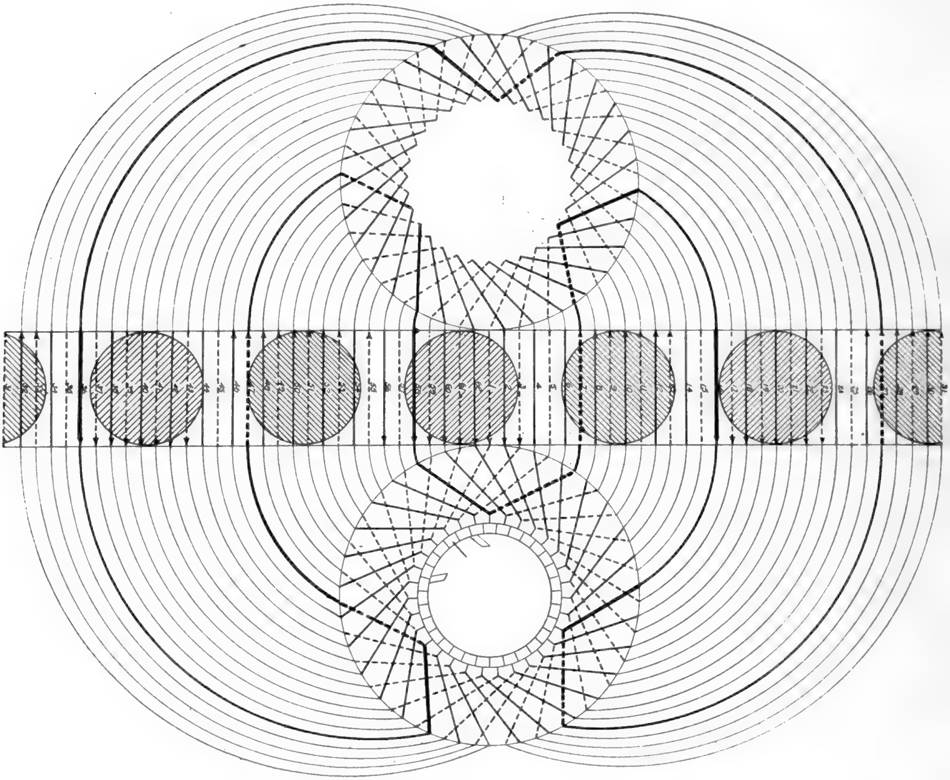


FIG. 170.—Developed Winding Diagram for 2-circuit 6-pole Armature, 62 Conductors. $yf=9$; $yb=11$.

fact that two-circuit windings tend toward requiring fewer and larger conductors as compared with multiple-circuit windings. This is often an attractive property from the point of view of the mechanical construction, and advantage may well be taken of it in small and moderate sized designs; but in large, multipolar generators, the best results will generally be obtained by means of multiple-circuit windings.

In selecting the precise number of conductors for two-circuit windings, and in interconnecting them, one must conform to the requirements of the formula

$$C = ny \pm 2,$$

in which

C = number of face conductors
n = " poles
y = " winding pitch."

If y (the mean pitch) is an odd number, it may be taken at the same value at both back and front ends, *i.e.* y (mean) may equal both yb and yf. Herein is another, although minor, point of difference from multiple-circuit windings. If y is an even number, yb and yf must be respectively 1 greater and 1 less (or *vice versâ*) than the mean value of y; or the back and front pitches may be 3 greater and 3 less, or 5 greater and 5 less, etc. These pitches will, however, generally be taken 1 greater and 1 less. It will be shown at a later stage, under what conditions it becomes of advantage to take yb and yf 3, 5, etc., greater and less than the mean pitch. In Fig. 170 the mean pitch is 10 ($y = 10$); the back pitch, yb, is equal to 9, and the front pitch, yf, to 11. The winding of Fig. 170 is again shown in Fig. 171, arranged according to the more usual and convenient conventions. An element of the winding is heavily lined in, in order to again impress upon the reader this distinguishing characteristic of a two-circuit winding. It will be noticed in Fig. 171 that only two sets of brushes are indicated, although the machine has six poles. For two-circuit windings, two brushes suffice, independently of the number of poles; but as many sets of brushes as there are poles are generally preferable. For multiple-circuit windings there *must* be as many sets of brushes as there are poles, the only alternative consisting in cross-connecting the commutator—a very undesirable practice, now generally abandoned.

Let us construct a 6-pole 2-circuit winding diagram with 58 conductors. We have $n = 6$; $C = 58$.

$$C = ny \pm 2$$
$$58 = 6y \pm 2$$
$$6y = 60 \text{ or } 56.$$

As 56 is not divisible by 6, we find that the only value for the mean pitch is

$$y = \frac{60}{6} = 10.$$

Let $yb=11$ and $yf=9$. The diagram is given in Fig. 172.

Suppose with the same value for the mean pitch, *i.e.* $y=10$, we had taken $yb=y+3$ (instead of $y+1$)$=10+3=13$, and $yf=y-3$ (instead of $y-1$)$=10-3=7$, then the diagram becomes that shown in Fig. 173.

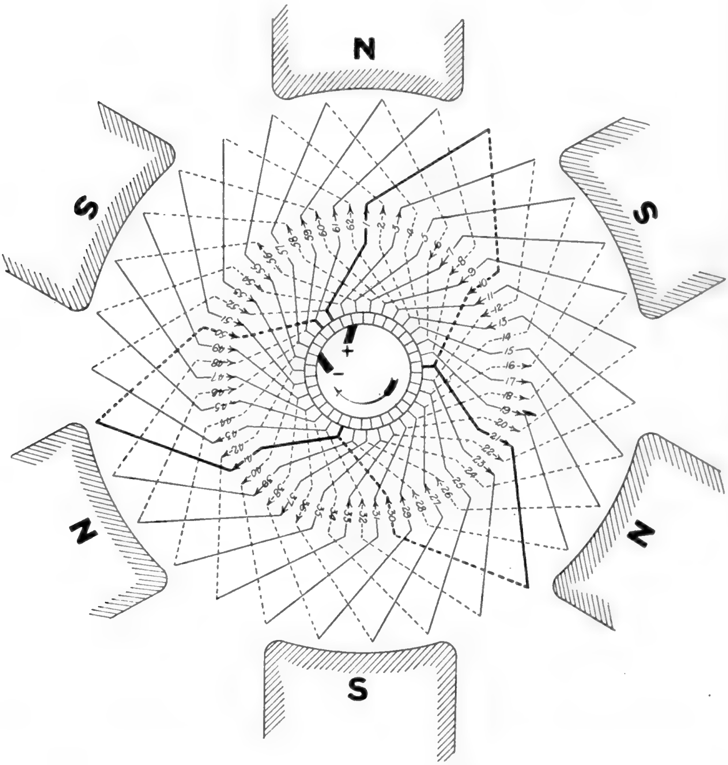


FIG. 171.—Winding Diagram for 2-circuit 6-pole Armature, 62 Conductors. $yf=9$; $yb=11$.

We may also take this same number of face conductors, *i.e.* 58, and construct 4-pole windings. For these cases $n=4$, and our formula becomes

$$58=4y\pm 2$$

$$y=\frac{60 \text{ or } 56}{4}=15 \text{ or } 14.$$

Let us take the solution which gives

$$y=15.$$

Then we may take

$$yb = 15 \text{ and } yf = 15 \text{ (Fig. 174)},$$

or

$$yb = 17 \text{ and } yf = 13 \text{ (Fig. 175)},$$

as both of these comply with our formula, which merely requires that y (mean) shall be equal to 15.

The use of such a small number of conductors, while it aids in the study of windings, is in some respects very misleading. Thus with the far larger numbers of conductors generally occurring in actual practice, these differences in the choice of pitch have a far smaller *percentage* effect on the winding; and hence may be employed when useful purposes are thereby served, as we shall soon show to occasionally be the case.

Windings with More than One Turn per Segment.

In the diagrams so far drawn, we have only had instances of windings with one turn per commutator segment; and we have represented the two face conductors, constituting the two sides of a turn, by numbered radial lines. When, as is necessary in many designs, instead of a single turn between two segments there is a coil of two, three, or more turns, we may still retain the same general scheme of constructing and numbering the winding diagram. In these cases we need merely make the mental reservation that each pair of radial lines, instead of representing the two conductors forming the two sides of a single *turn*, represents the two *groups* of conductors forming the two sides of a *coil.* Were we to represent the entire number of conductors by radial lines, the enormous number of lines and connections would not only require, in preparation, a large amount of time and labour, but the result would be a very confusing diagram.

In Figs. 176 and 177 are shown respectively a single three-turn coil and the corresponding commutator segments for a multiple-circuit winding (Fig. 176), and a two-circuit winding (Fig. 177). Below these, in Figs. 178 and 179, are shown the corresponding diagrammatic representation which, in complete diagrams, it is preferable to adopt, and in which the group of three face conductors is in each case replaced by a single line; the lines corresponding to the front end connections of the unrepresented turns being suppressed.

In Fig. 330, p. 278, is shown a section through the slot of a four-turn-per-coil winding, with three segments per slot. Such

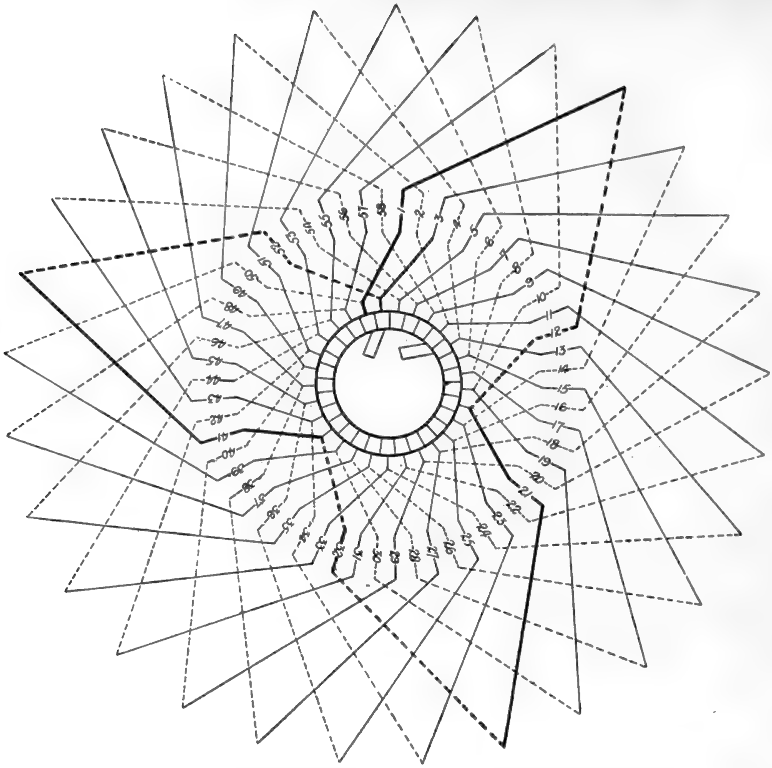


FIG. 172.—Winding Diagram for $n=6$; C=58 ; $yf=9$; $yb=11$.

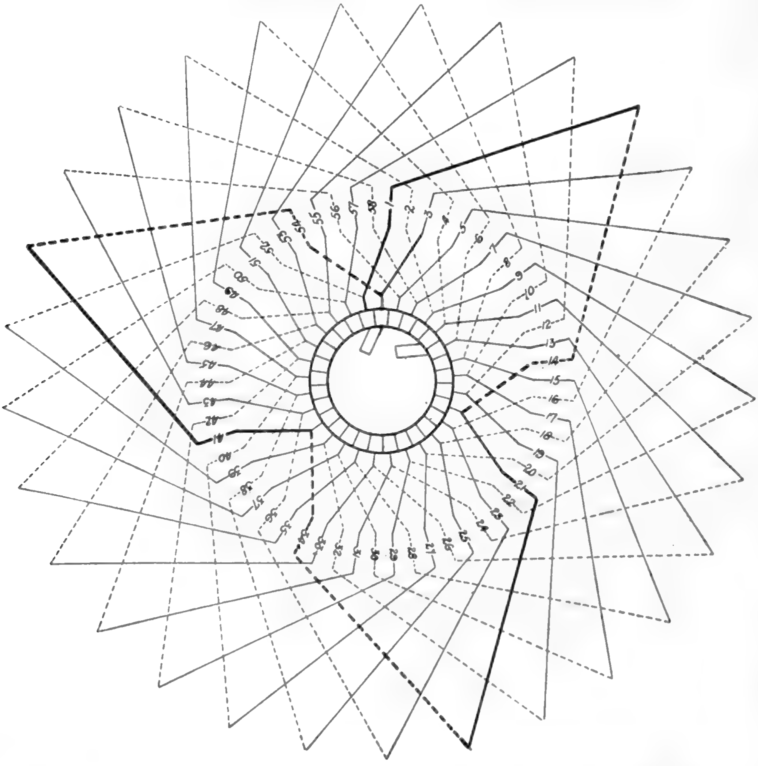


FIG. 173.—Winding Diagram for $n=6$; C=58 ; $yf=7$; $yb=13$.

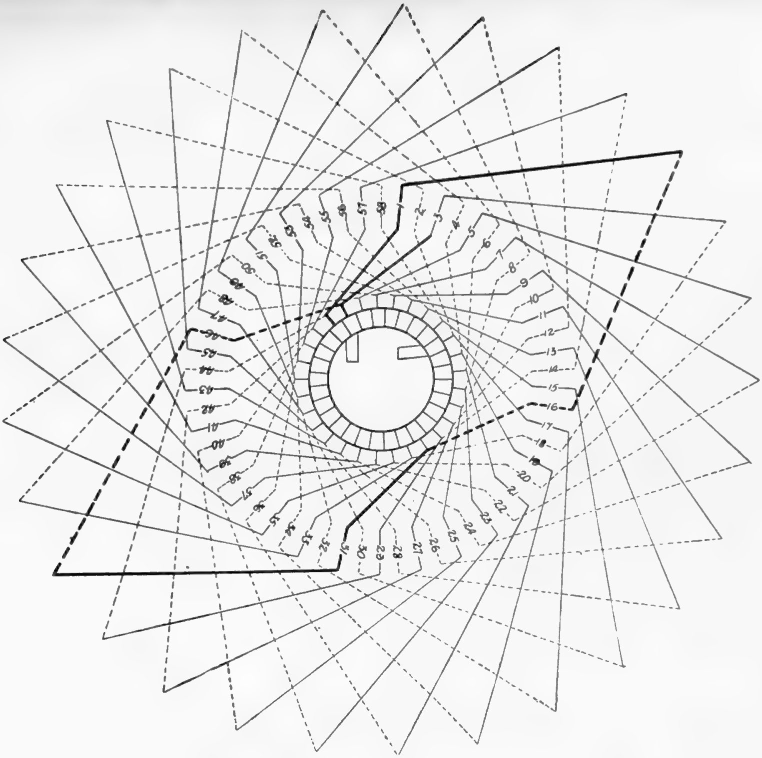


FIG. 174.—Winding Diagram for $n=4$; $C=58$; $yf=15$; $yb=15$.

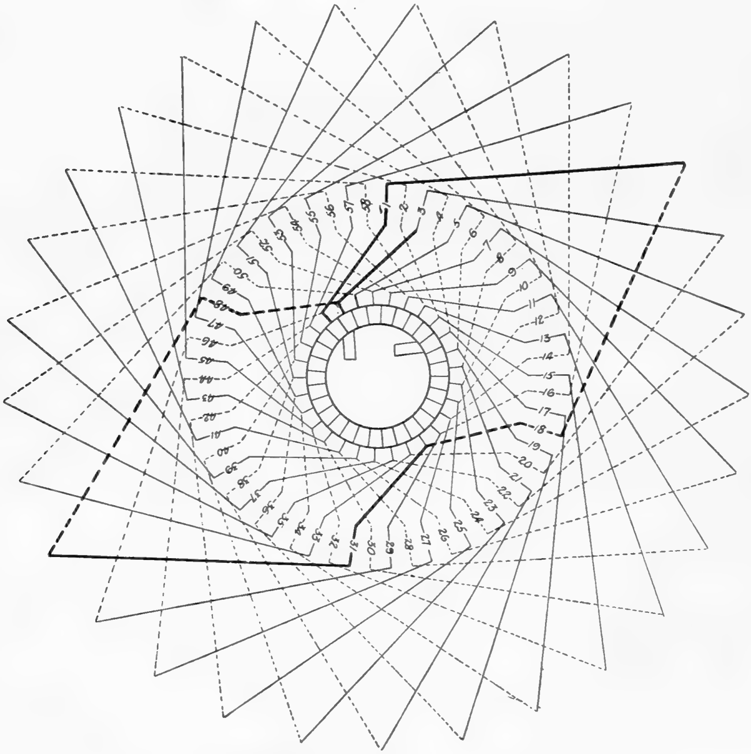


FIG. 175.—Winding Diagram for $n=4$; $C=58$; $yf=13$; $yb=17$.

windings are, so far as location in the slot is concerned, susceptible to a number of arrangements; that shown in Fig. 330 is, however, the most customary. The upper twelve conductors are, before being placed in the slot, made up into a twelve-turn coil with six ends, in the manner shown in Fig. 331, p. 279, or in Figs. 308 and 309, p. 264.

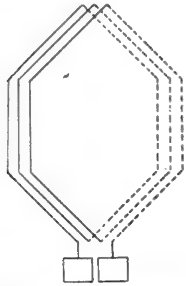


FIG. 176.—Multiple-circuit Winding —three-turn coil.

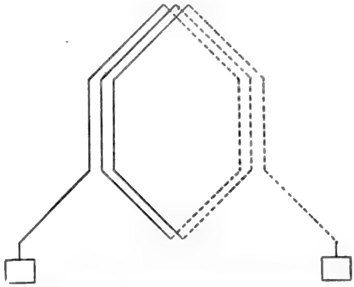


FIG. 177.—Two-circuit Winding—three-turn coil.

Now we come to the question of the influence of the number of slots on the choice of *yf* and *yb* for two-circuit windings. Suppose that we wish to design a 4-pole winding for a 57-slot armature, and to employ the coil illustrated in Figs. 330 and 331. There are to be three segments per slot, and four turns per segment;

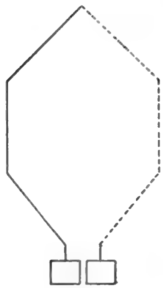


FIG. 178.

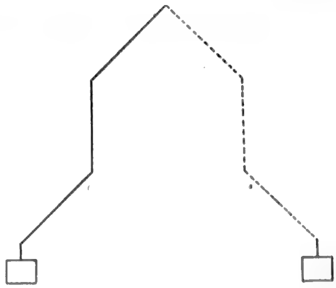


FIG. 179.

Single turns representing three-turn coils.

thus there are six terminals per coil. The twelve upper conductors of one slot constitute one side of a compact "coil," of which the other side shall comprise the twelve lower conductors of some other slot. While there are actually

$$57 \times 24 = 1368$$

face conductors, we shall consider each group of four conductors to be replaced by a single conductor. Thus we have 6 "equivalent" conductors per slot, or

$$57 \times 6 = 342$$

face conductors.

$$C = ny \pm 2$$
$$342 = 4y \pm 2$$
$$y = \frac{340 \text{ or } 344}{4} = 85 \text{ or } 86.$$

Let us examine whether it will be practicable to use

$$yf = 85 \text{ and } yb = 85.$$

We should go from 1 to 86 at the back end, and also from 3 to 88 and from 5 to 90. Since 1, 3, and 5, together with 86, 88, and 90, must constitute a form-wound coil; then if 1, 3, and 5 occupy the top half of some slot, say slot 1, then 86, 88, and 90 must occupy the bottom half of some other slot. Slot 1 contains conductors 1, 2, 3, 4, 5, and 6. The slot containing conductors No. 86, 88, and 90 in its lower half, must contain conductors 85, 87, and 89 in its upper half. Thus the first 90 conductors must occupy an integral number of slots. Evidently this condition is fulfilled, for

$$\frac{90}{6} = 15.$$

Thus while conductors 1, 3, and 5 occupy the top half of slot 1, conductors 86, 88, and 90 occupy the bottom half of slot 15. But suppose we had required five segments per slot, then

$$C = 10 \times 57 = 570$$
$$570 = 4y \pm 2$$
$$4y = 572 \text{ or } 568$$
$$y = 143 \text{ or } 142.$$

Suppose we wish to take $yf = 143$ and $yb = 143$. Then conductors 1, 3, 5, 7, and 9 go to conductors 144, 146, 148, 150, and 152. Thus if 1 is the upper left-hand conductor of slot 1, then 152 ought to be the slot holding the lower and right-hand side of the coil; but since 152 is not divisible by 10 without a remainder, that is not the case, and hence it will not do to employ a pitch of 143 at both ends. But if we change yb to 141, then we have 1, 3, 5, 7, and 9 connected to 142, 144, 146, 148, and 150. Hence while conductor No. 1 is the upper left-hand conductor of slot 1, conductor No. 150 is the lower right-hand conductor of slot 15, which is the required condition. The component turns will also

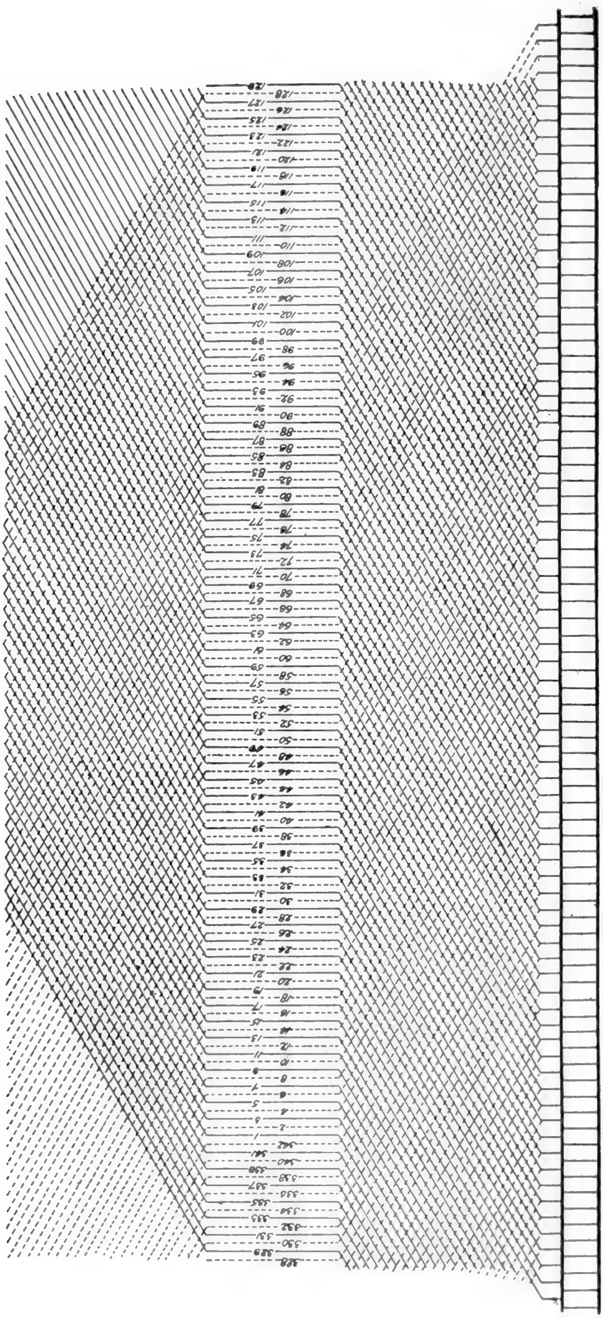


FIG. 180.—Two-circuit Winding with Three-turn Coils represented by Single Turns.

have this same pitch of 141 at the front end; but the front end pitch, so far as relates to the interconnection of the coils, will be

$$yf = 143.$$

Thus y (mean) $= 142$, $yf = 143$, $yb = 141$.

A development of a portion of this winding is shown diagrammatically in Fig. 180, the front connections of the component turns not being shown; and the three face conductors forming one side of a single (four turn) coil being represented by a single radial line. This conforms to the diagram which is found most convenient in practice, in representing such a winding.

A little reflection will show that the labour of preparing a complete diagram showing each individual turn would generally be prohibitive, and furthermore, that it would not be conducive to clearness. It is preferable to make the above indicated mental reservation, and comply with the more simple practice corresponding to the diagram of Fig. 180.

Multiplex Windings.

As already stated, both two-circuit and multiple-circuit windings may be multiplex. As multiplex windings are not to be recommended except in special cases, no great amount of space will be devoted to their consideration.

MULTIPLE-CIRCUIT MULTIPLEX WINDINGS.

Fig. 181 is a diagram of an eight-pole multiple-circuit duplex winding. The winding shown is doubly re-entrant, that is to say, it consists of two entirely independent conducting systems completely insulated from one another. These are represented by black and red lines in the diagram. The winding has 300 face conductors, 150 belonging to each winding. The front end pitch is 35, and the back end pitch is 39. In multiple-circuit multiplex windings there will be a number of independent windings equal to the greatest common factor of $\frac{C}{2}$ and m, where C is equal to the number of face conductors, and m is equal to the number of windings. In the present instance we are considering a duplex winding. Hence $m = 2$. $\frac{C}{2}$ is equal to 150. The greatest common factor of 150 and 2 is 2. Hence the winding is a doubly re-entrant duplex winding. The pitches must be odd, and must differ from one another by $2m$. In this case, $2m$ is equal to 4. Hence, if the front end pitch is taken at 35, then the back end pitch should be taken as $35+4$, or 39. The mean pitch should be approximately equal to the number of face conductors divided by the number of poles. In this case the mean pitch should be approximately equal to $\frac{300}{8}$, or 37·5. It is taken as $\frac{35+39}{2}=37$. By keeping the front and back pitches the same as in the diagram of Fig. 181, *i.e.* equal to 35 and 39 respectively, but employing only 298 conductors, as in the diagram of Fig. 182, we obtain a singly re-entrant duplex winding. This is a consequence of the rule already enunciated; for $C=\frac{298}{2}=149$, and $m=2$, and the greatest common factor of 149 and 2 is 1, *i.e.* the winding is singly re-entrant. Hence it is impracticable to show it in two different colours, as it is a symmetrical winding in which no conductors belong more especially to one half than to the other half of the duplex winding. The precise designation of these windings is as follows:—

Fig. 181—Eight-circuit, doubly re-entrant duplex winding.

Fig. 182—Eight-circuit, singly re-entrant duplex winding.

We may also have triplex, quadruplex, quintuplex, etc., windings, and these may have various degrees of re-entrancy, Thus a triplex winding may be either singly or triply re-entrant, and a quadruplex winding may be either singly, doubly, or quadruply re-entrant.

In Figs. 183 and 184 are shown eight-circuit triply and singly re-entrant triplex windings with 300 and 298 face conductors respectively. In both cases the pitches are 35 and 41.

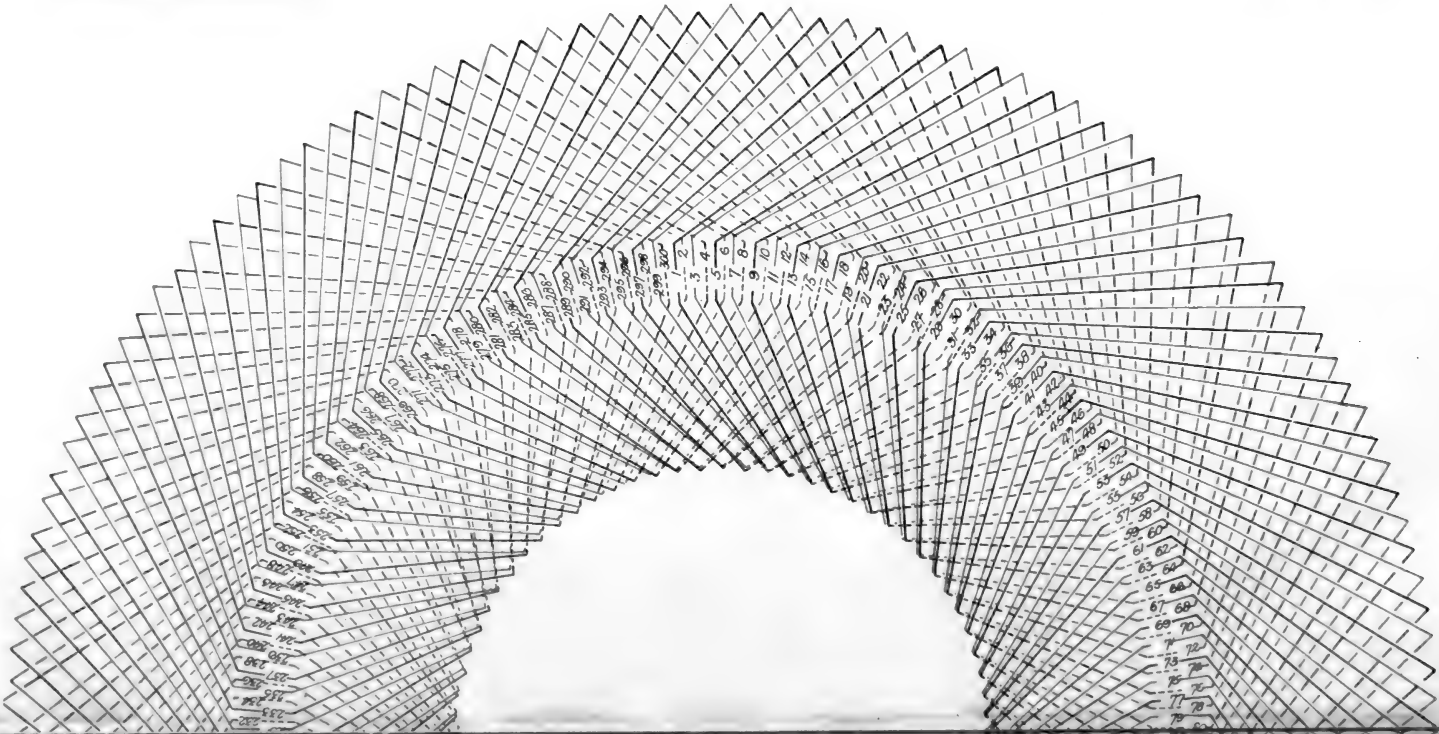
TWO-CIRCUIT MULTIPLEX WINDINGS.

The fundamental formula for two-circuit multiplex windings is

$$C=ny\pm 2m,$$

where C, n y and m have the same significance as heretofore. The m windings will comprise a number of independently re-entrant windings, equal to the greatest common factor of y and m.

In Figs. 185 and 186 are shown eight-pole, two-circuit, duplex windings, each with 300 face conductors. In Fig. 185 the pitch is 37 at the front end and 39 at the back end, the mean pitch thus being 38. Hence, as $y=38$ and $m=2$, the winding is



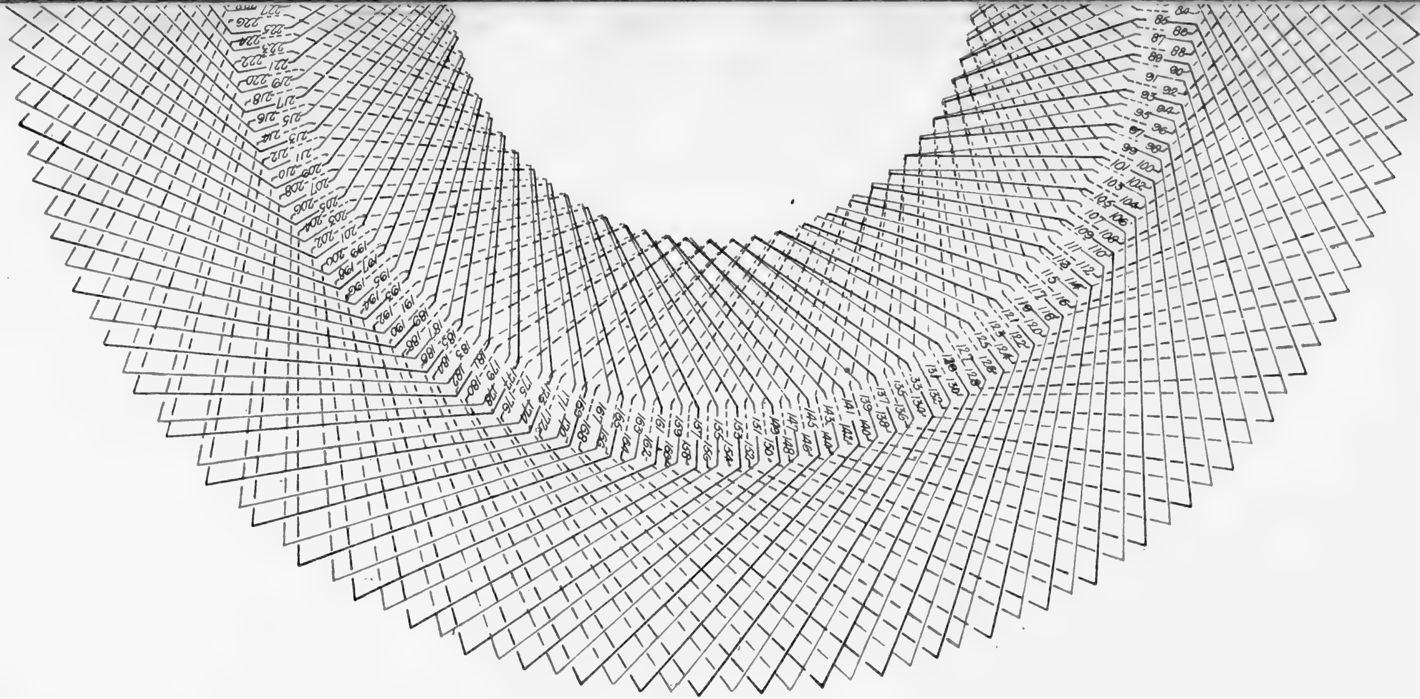
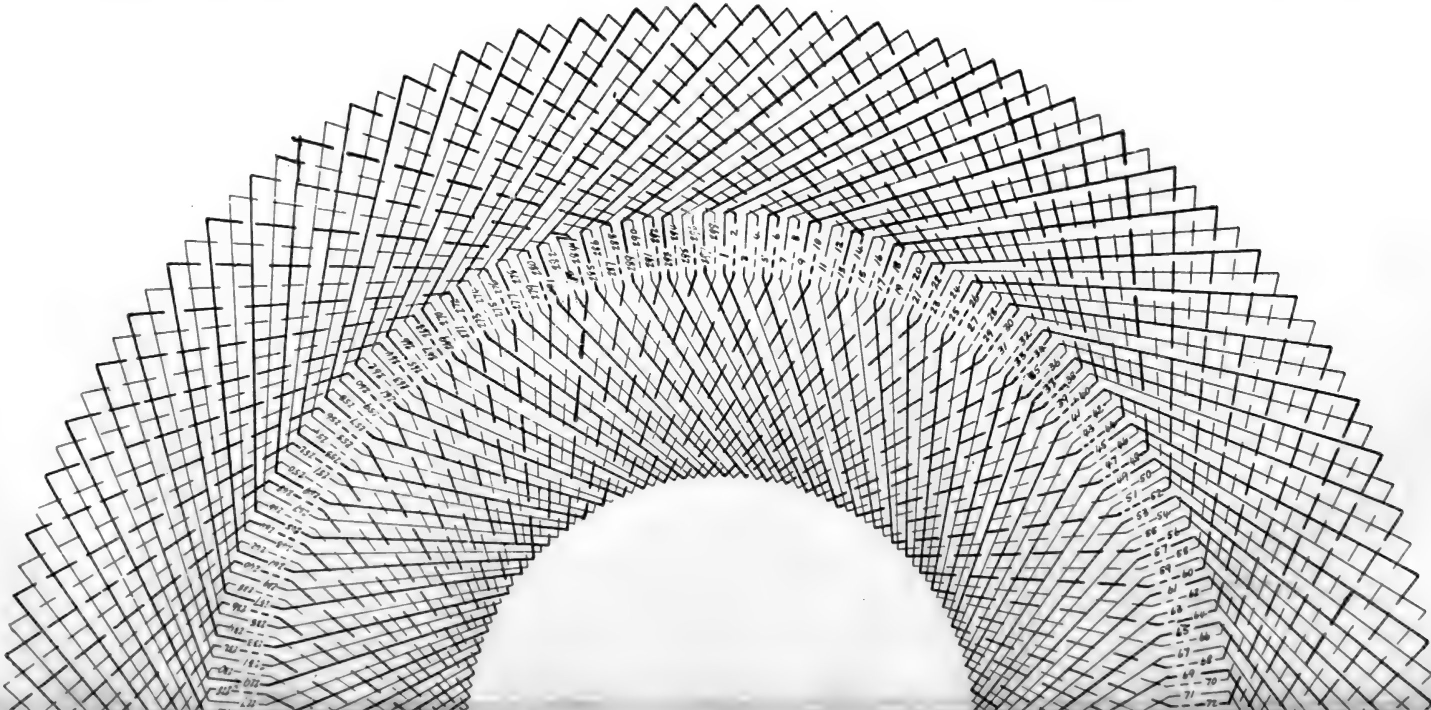


FIG. 181.—Eight-pole, Multiple-circuit, Doubly Re-entrant Duplex Winding.



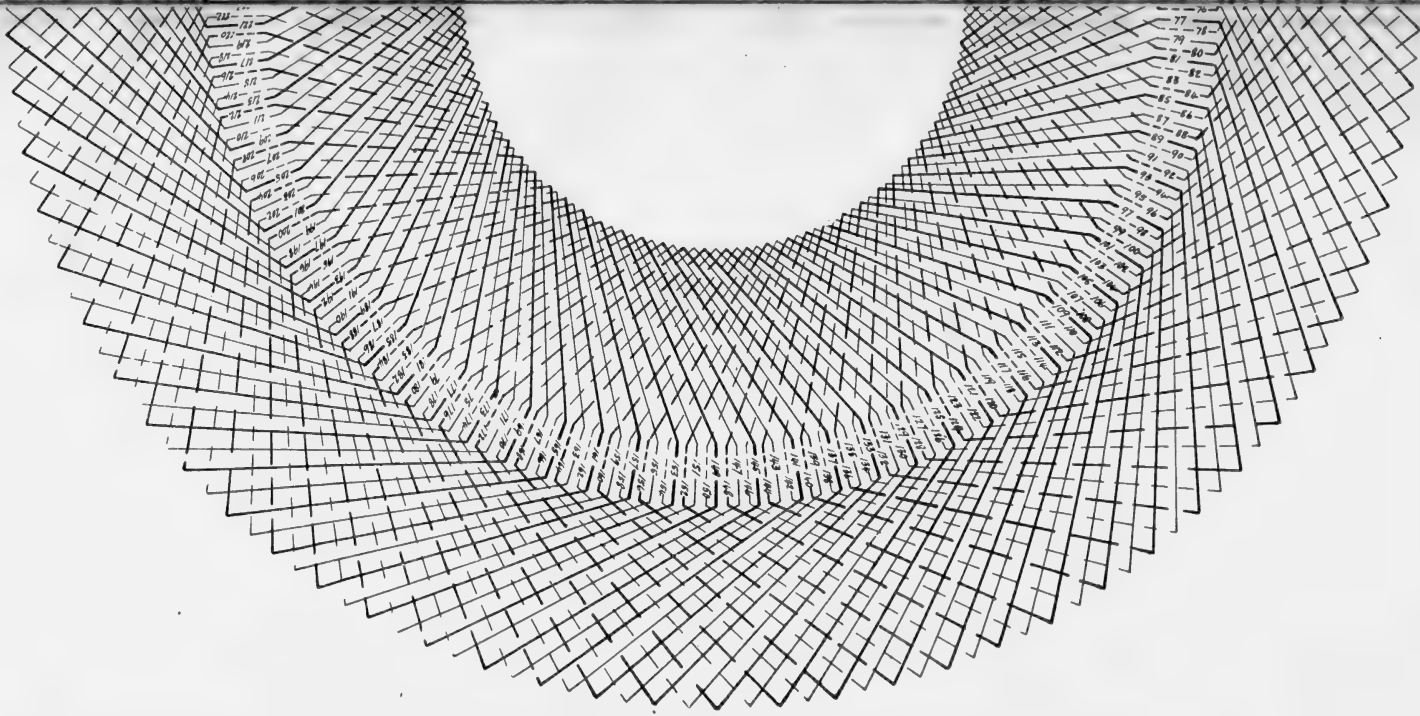
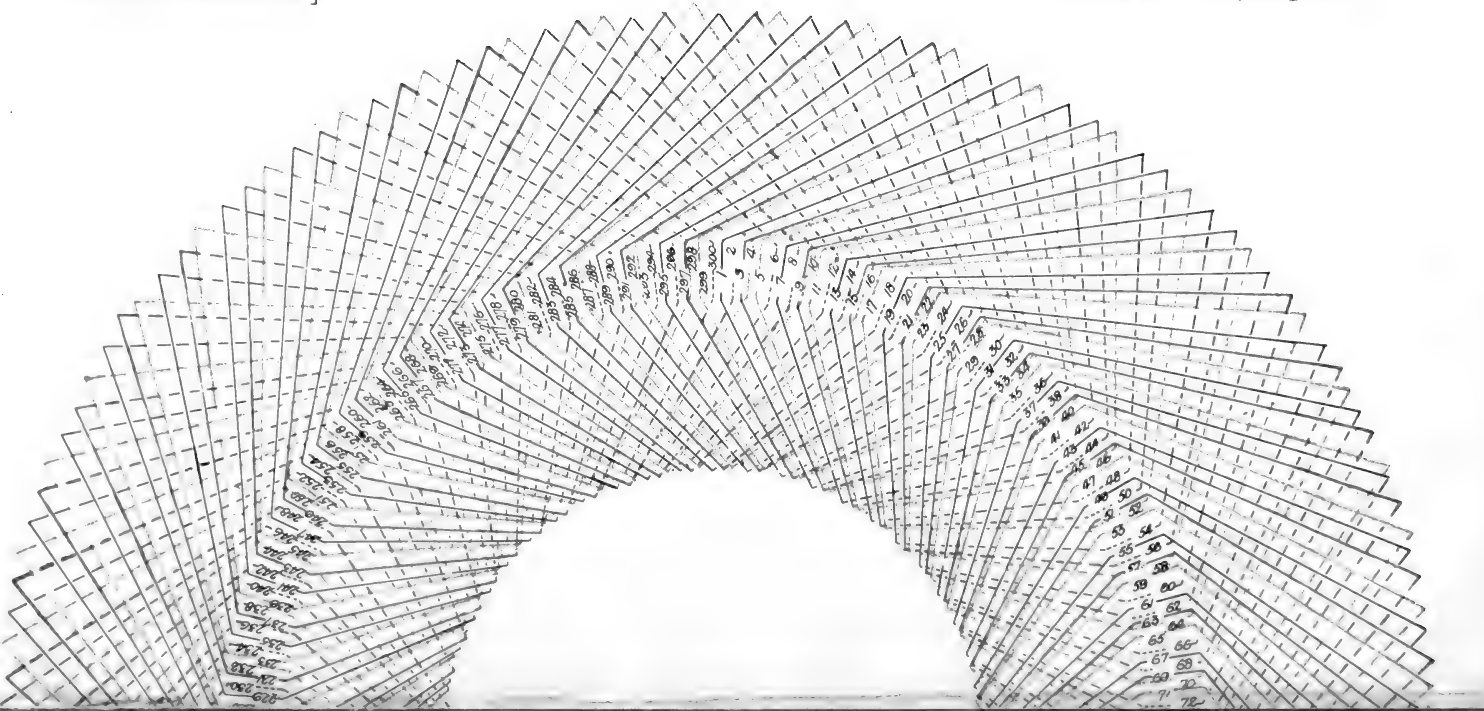


Fig. 182.—Eight-pole, Multiple Circuit, Singly Re-entrant Duplex Winding.



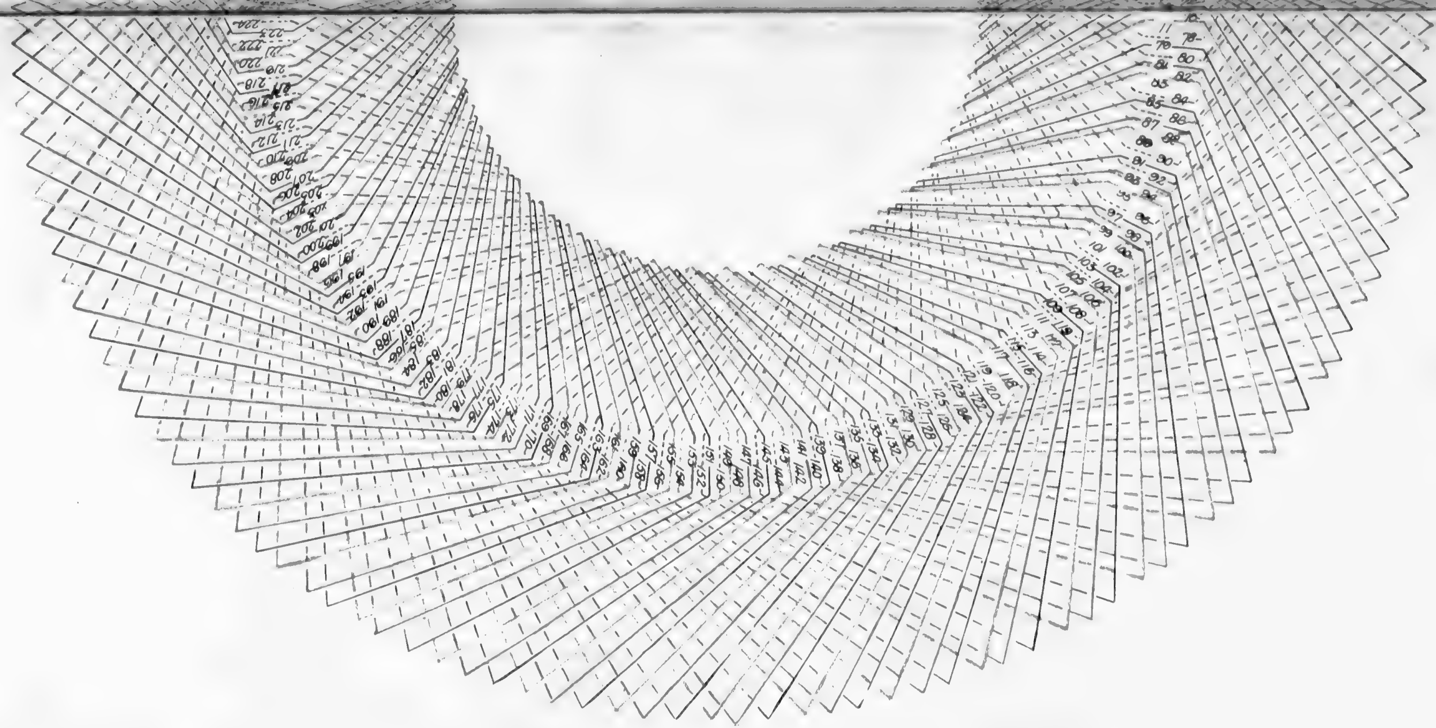
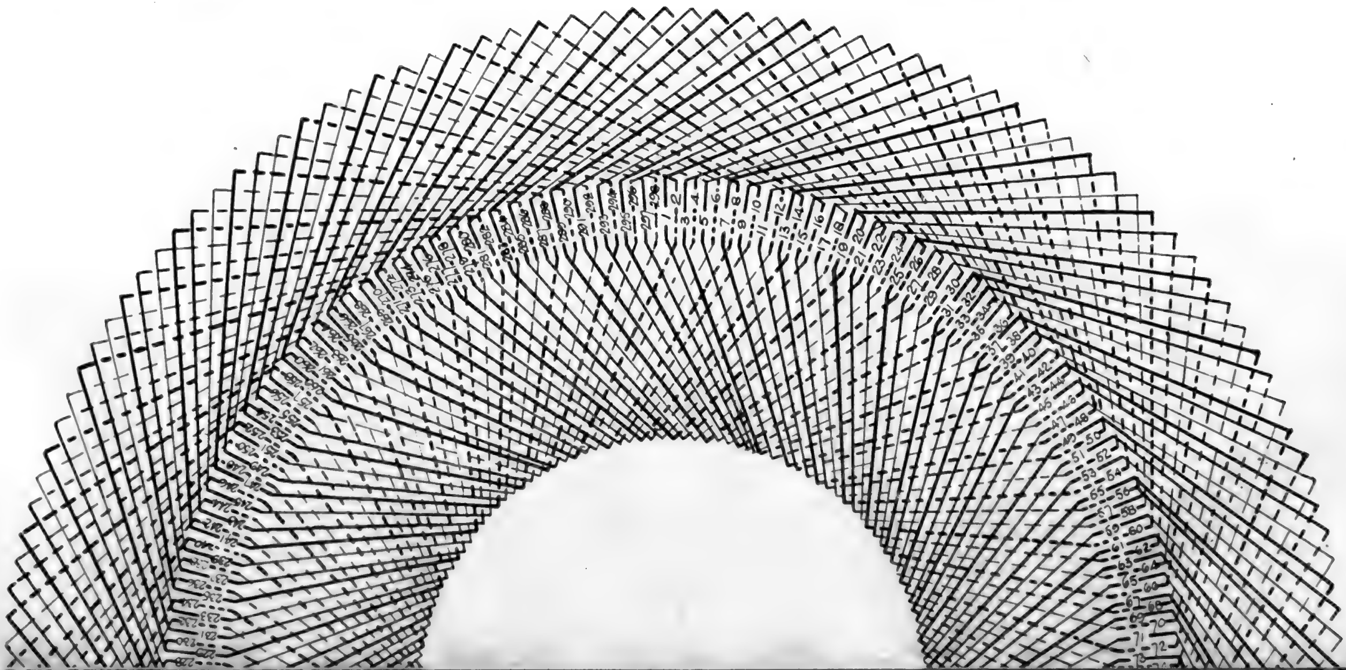


FIG. 183.—Eight-pole, Multiple-circuit, Triply Re-entrant Triplex Winding.



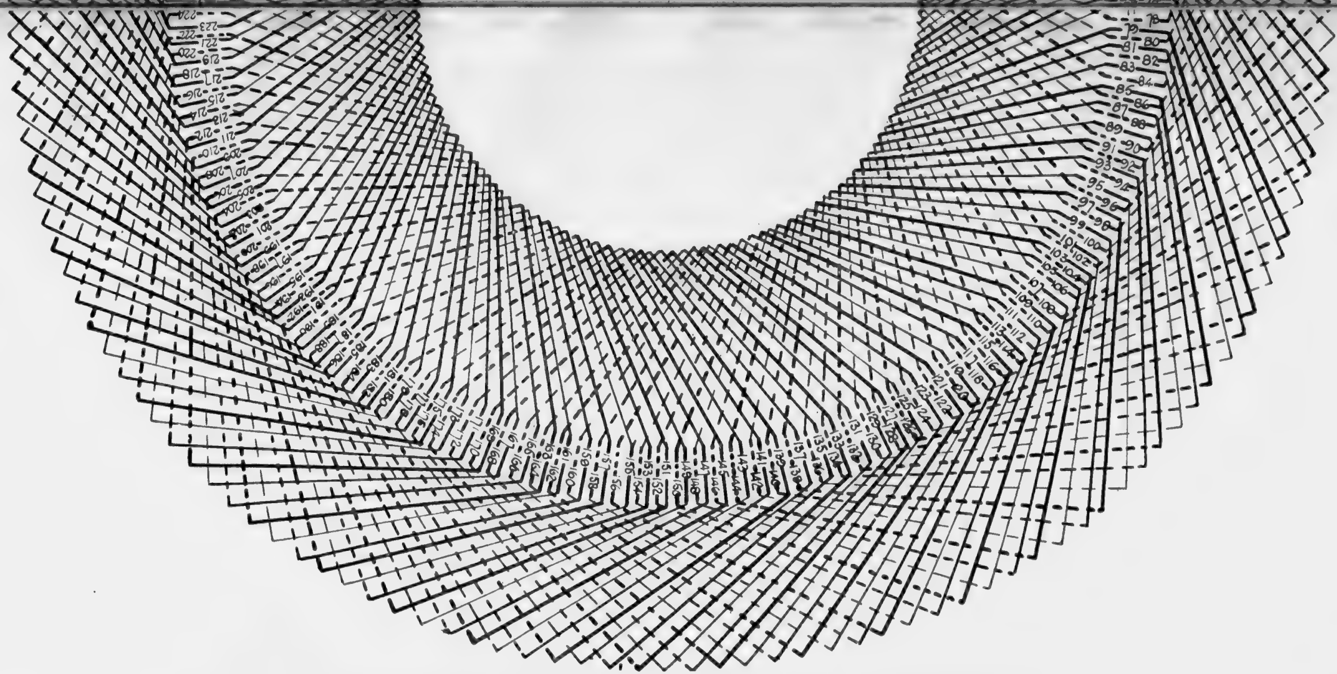
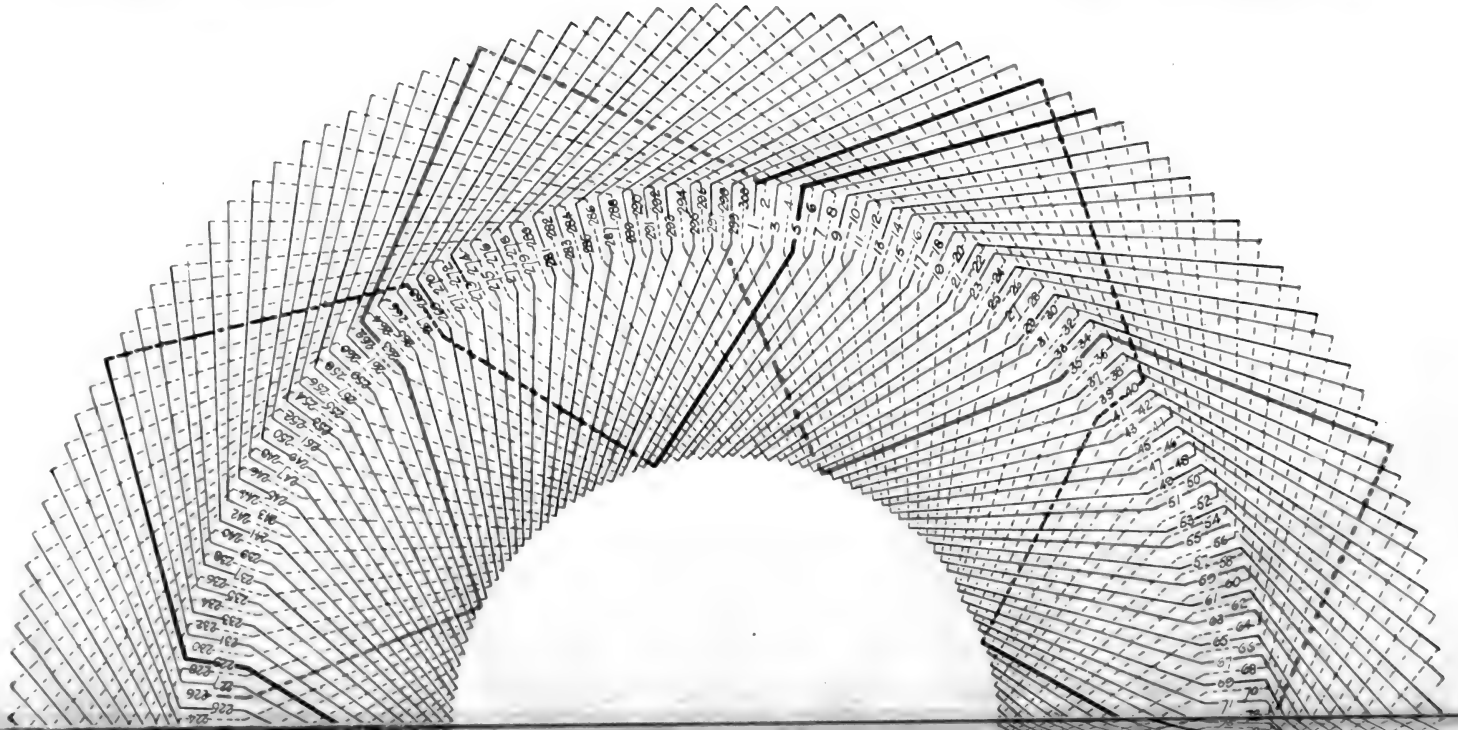


FIG. 184.—Eight-pole, Multiple Circuit, Singly Re-entrant Triplex Winding.



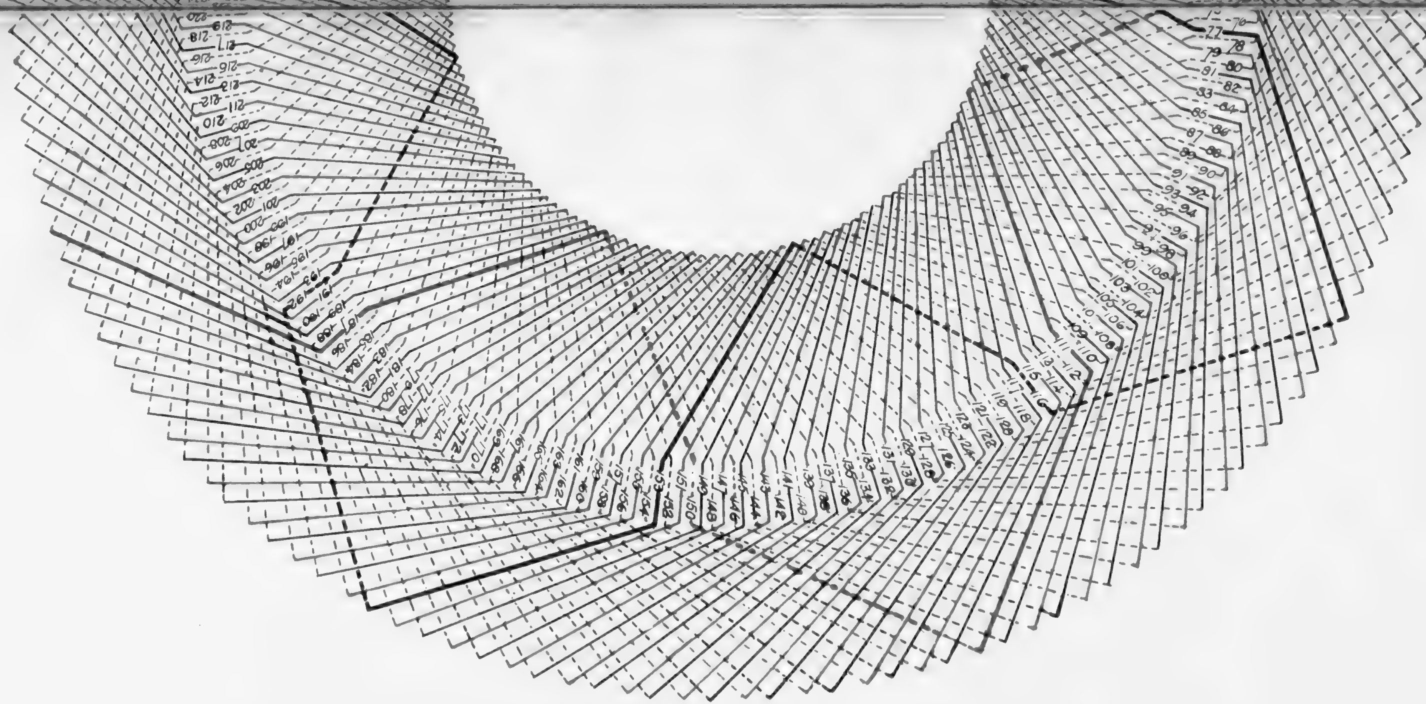
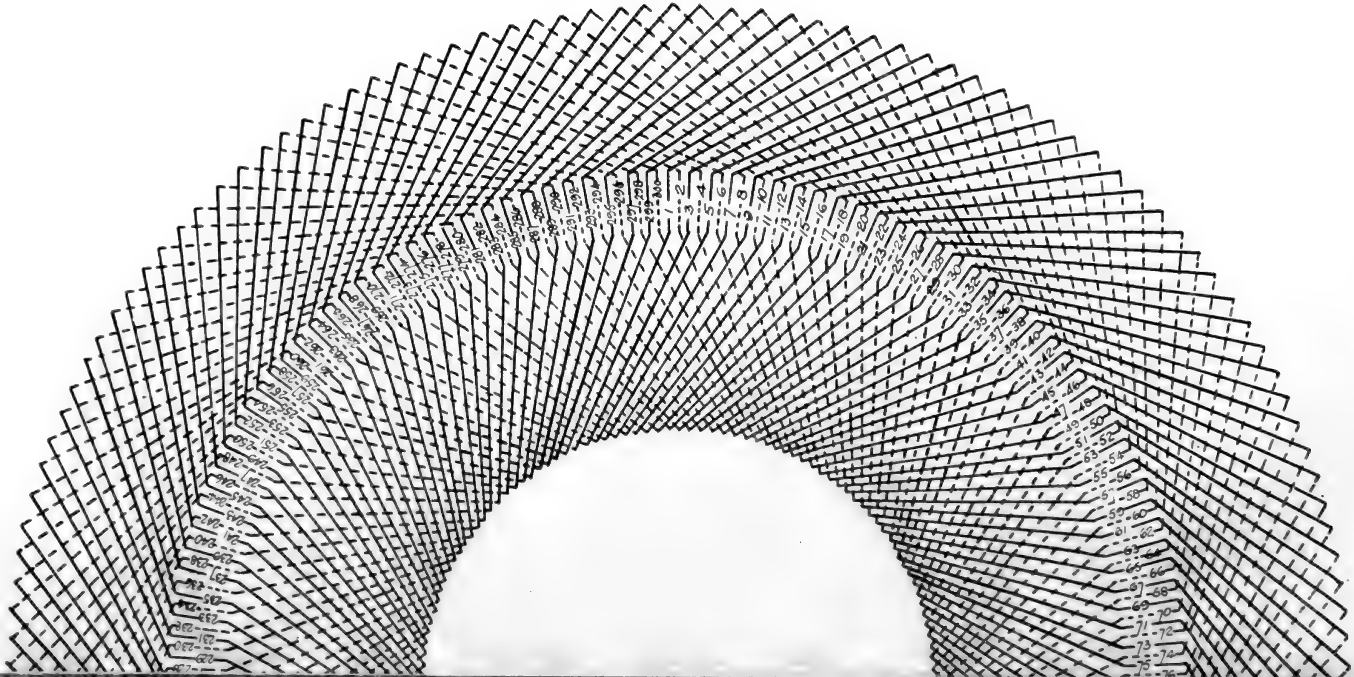


FIG. 185 —Eight-pole, Two-circuit, Doubly Re-entrant Duplex Winding.



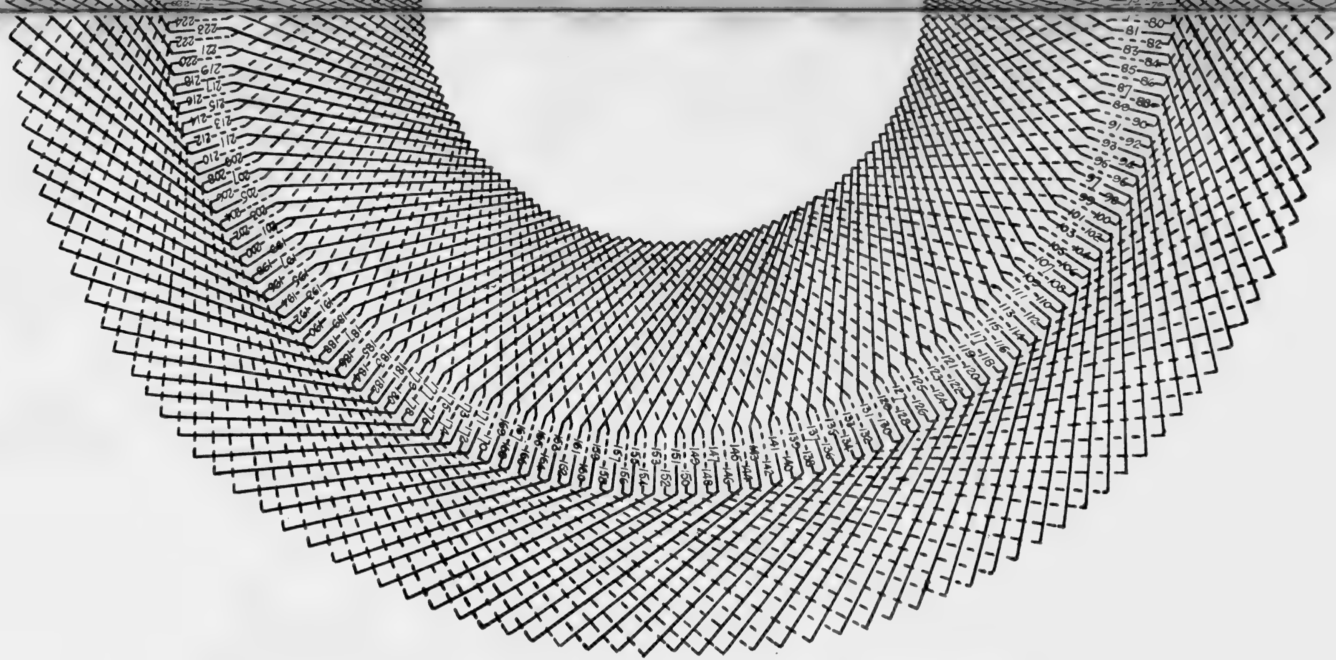
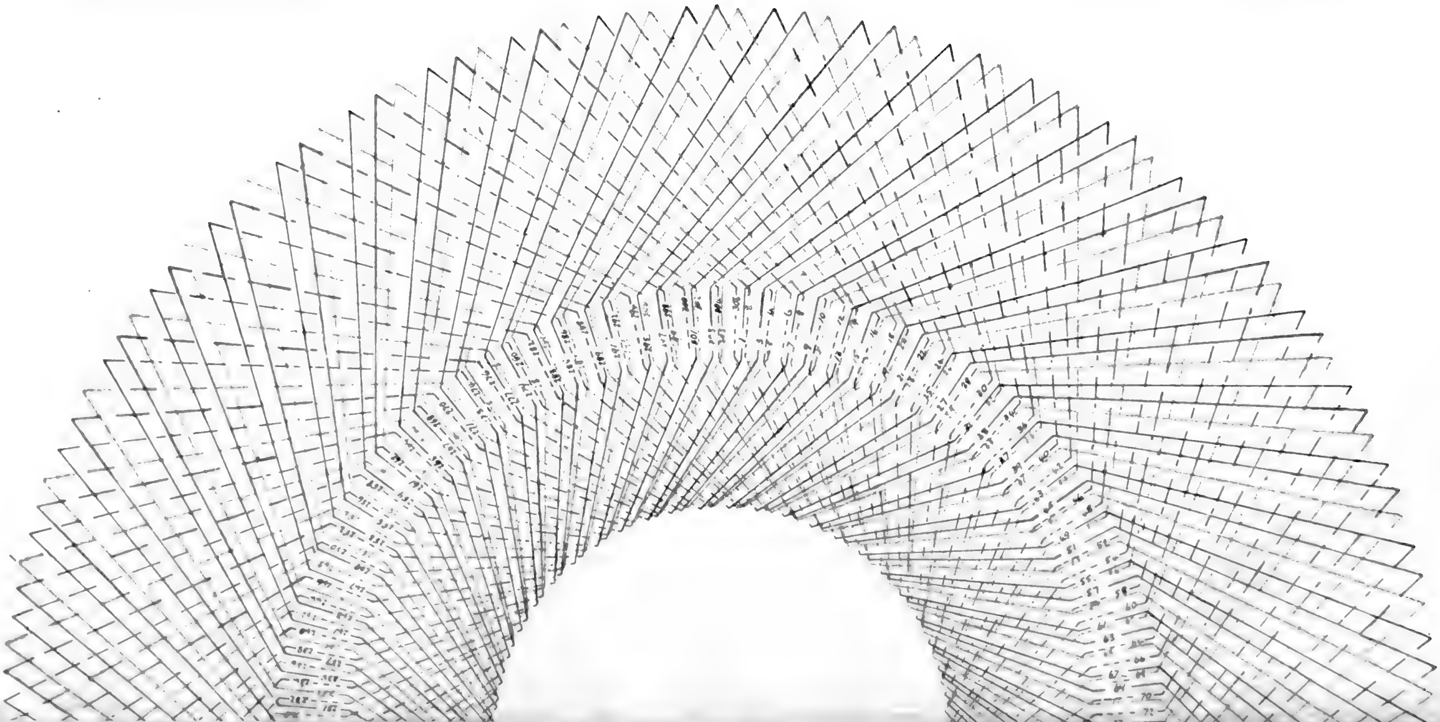


FIG. 186.—Eight-pole, Two-circuit, Singly Re-entrant Duplex Winding.



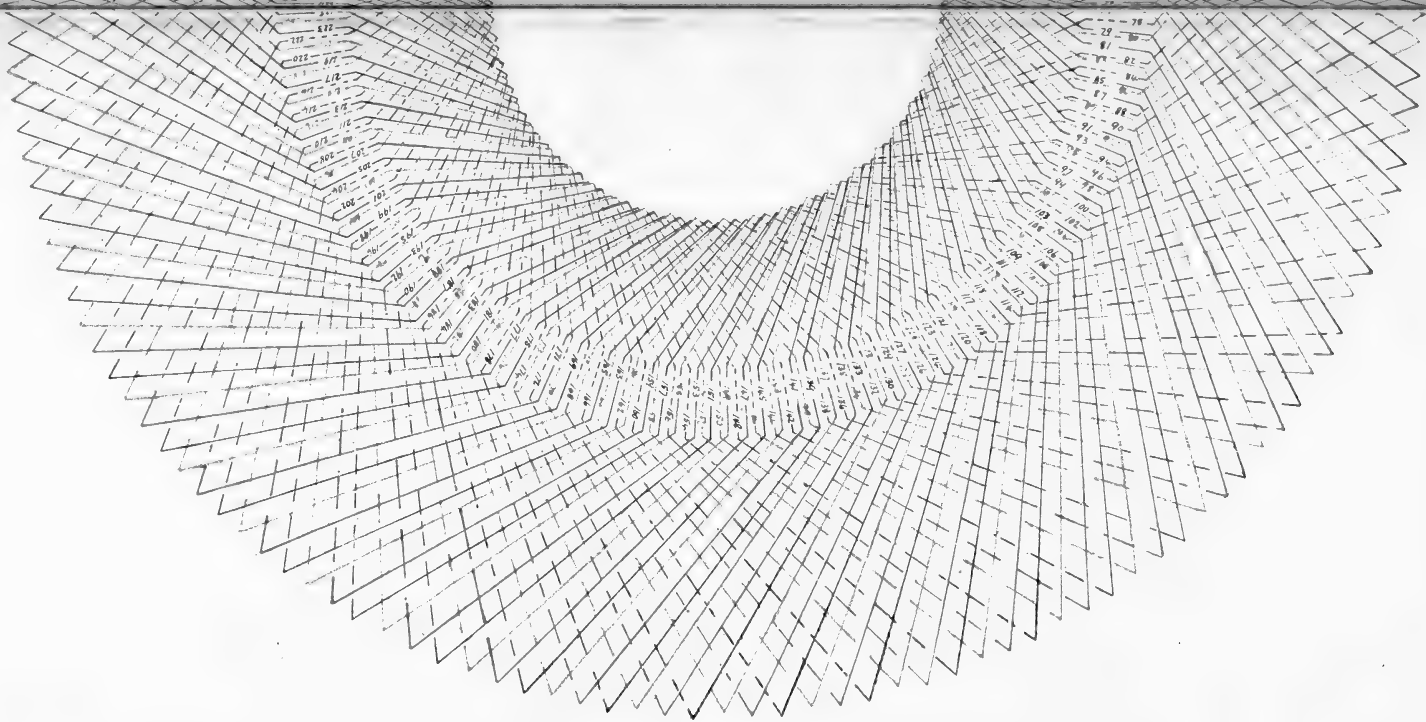
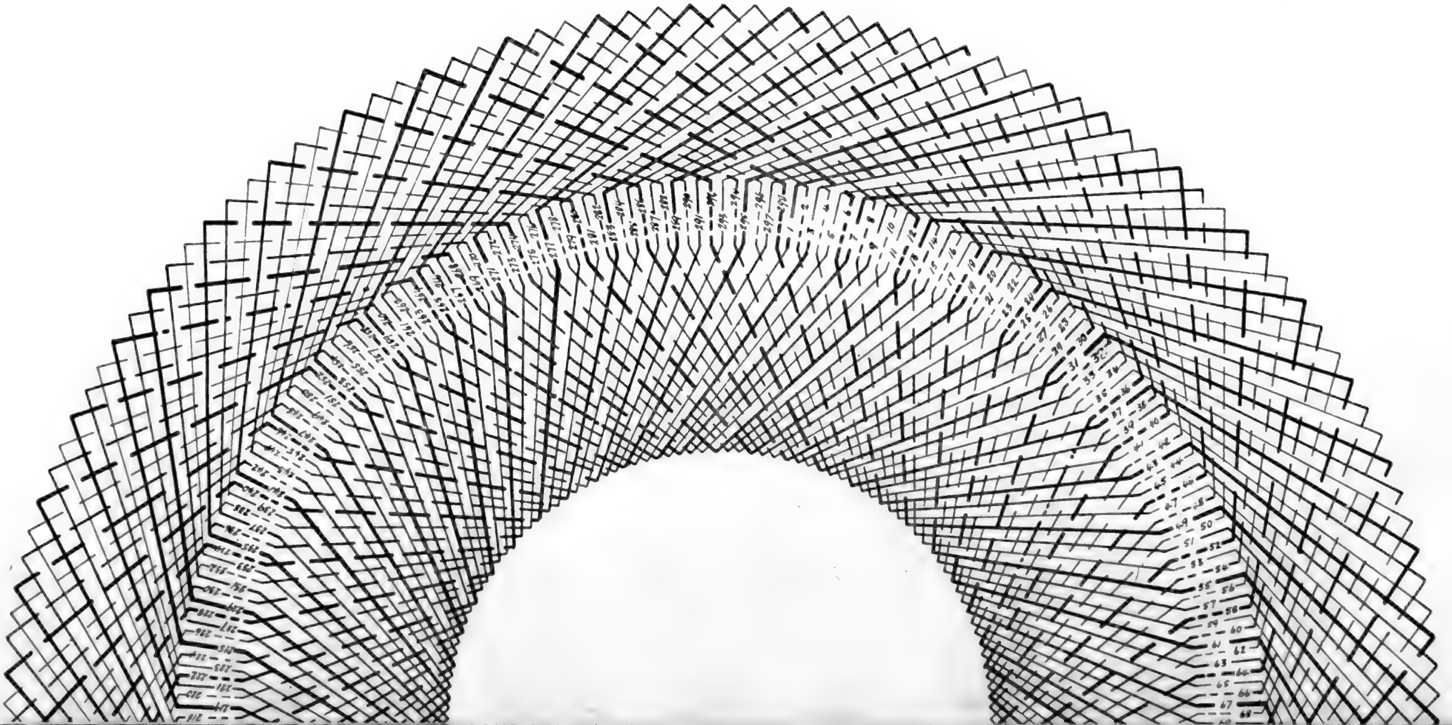


Fig. 187.—Eight-pole, Two-circuit, Triply Re-entrant Triplex Winding.



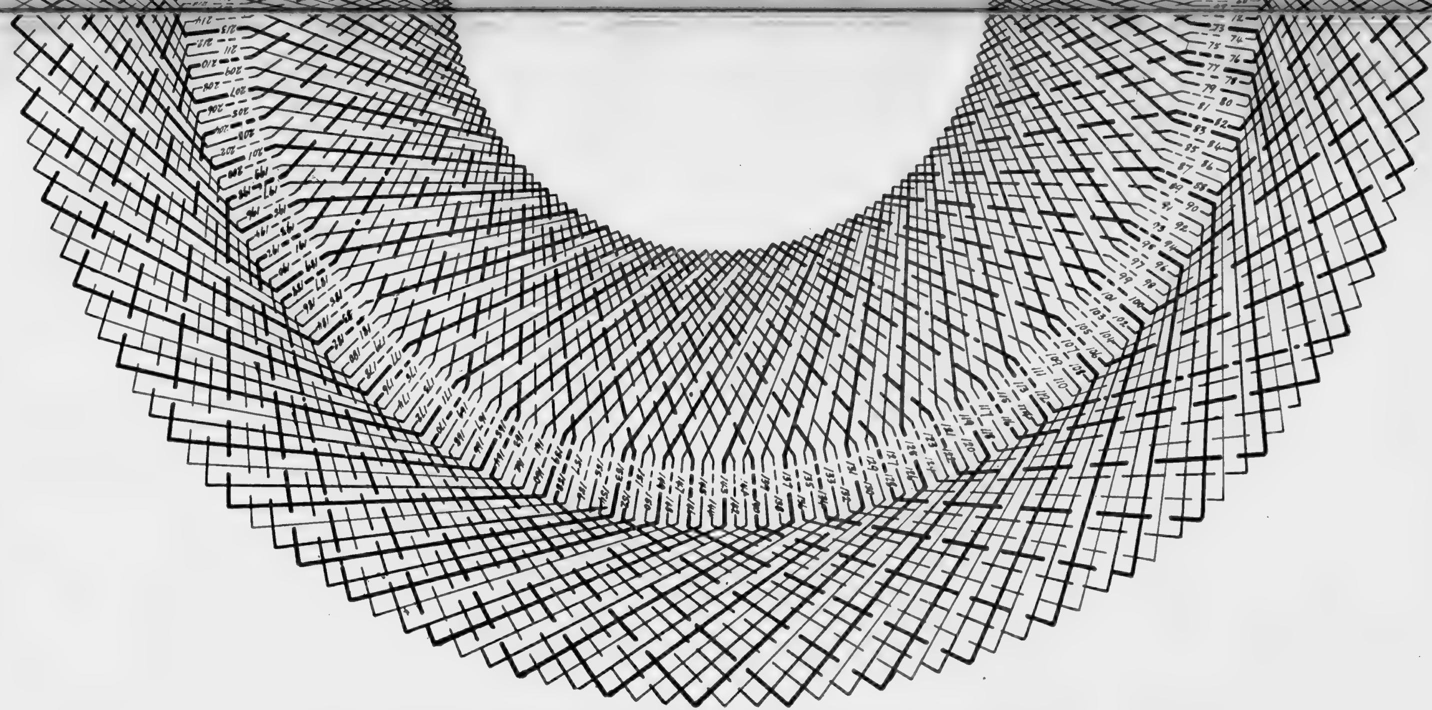


FIG. 188.—Eight-pole, Two-circuit, Singly Re-entrant Triplex Winding.

doubly re-entrant, since the greatest common factor of 38 and 2 is equal to 2.

The formula $c = ny \pm 2m$ is complied with, since we have

$$\begin{aligned} 300 &= 8 \times 38 - 2 \times 2 \\ &= 304 - 4 \\ &= 300 \end{aligned}$$

In Fig. 186 the pitch is 37 at both ends, and since the greatest common factor of 37 and 2 is 1, the winding is singly re-entrant. That the formula $C = n\,y \pm 2m$ is also complied with in this case, may be seen by substituting as follows:—

$$\begin{aligned} 300 &= 8 \times 37 + 2 \times 2 \\ &= 296 + 4 \\ &= 300. \end{aligned}$$

In Figs. 187 and 188 are shown eight-pole, two-circuit triplex windings. The values of C, n, y and m, and the re-entrancy, are as follows:—

	Fig. 187.	Fig. 188.
Number of face conductors (C) .	306	298
,, poles (n) . . .	8	8
Degree of multiplexity (m) . .	3	3
Front end pitch (yf) . . .	39	37
Back ,, ,, (yb) . . .	39	39
Mean pitch (y) . . .	39	38
Greatest common factor of y and m .	3	1
Re-entrancy	3	1

As to compliance with the formula $C = ny \pm 2m$ we have:

Fig. 187.

$$\begin{aligned} 306 &= 8 \times 39 - 2 \times 3 \\ &= 312 - 6 \\ &= 306 \end{aligned}$$

Fig. 188.

$$\begin{aligned} 298 &= 8 \times 38 - 2 \times 3 \\ &= 304 - 6 \\ &= 298 \end{aligned}$$

One could develop an endless number of interesting varieties of these windings, but inasmuch as they are at present of much less general utility than simplex windings, it would be out of place in the present treatise to devote much more space to their consideration. New developments in the design of dynamo electric machinery might, however, bring these windings to the front. The last winding of this type which we shall show is that of

Fig. 189. It is a six-pole, two-circuit, triply re-entrant sextuplex winding.

$$n=6 \qquad m=6$$

In order that it shall be triply re-entrant, it is necessary that

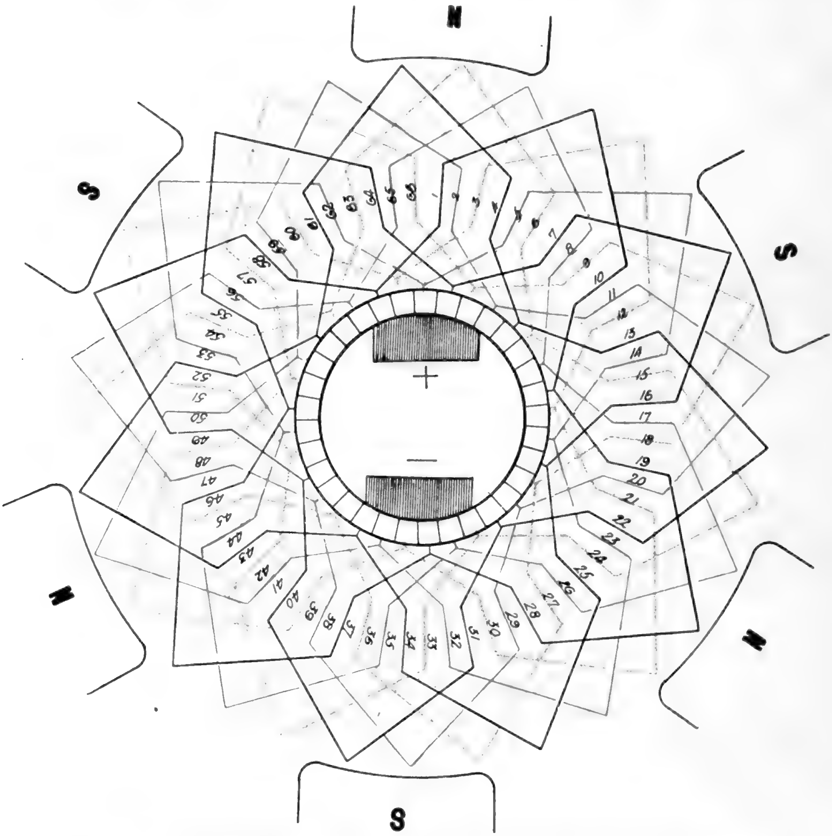


FIG. 189.—Six-pole, Two-circuit, Triply Re-entrant Sextuplex Winding.

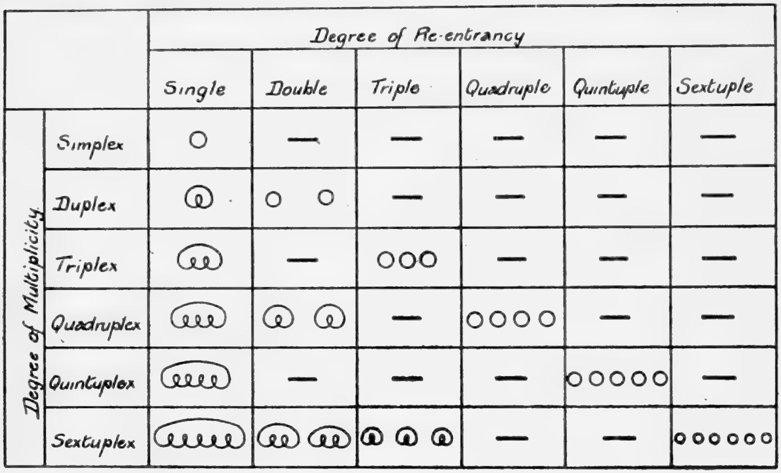
the greatest common factor of m and y shall be 3. Therefore y is taken equal to 9,

$$\begin{aligned} C &= n\,y \pm 2m \\ &= 6\times 9 \pm 2\times 6 \\ &= 42 \text{ or } 66. \end{aligned}$$

Sixty-six conductors have been taken. The three independent circuits are shown respectively in black, red and blue. In the following table is shown a system of symbols for use in representing multiplex windings. The symbols indicate the degree of multiplicity and the re-entrancy. They are equally applicable to two-circuit and multiple-circuit windings.

TABLE XI.

SHOWING MULTIPLICITY AND RE-ENTRANCY OF MULTIPLEX WINDINGS.



SPECIAL TWO-CIRCUIT WINDINGS.

From the formula

$$C = ny \pm 2$$

for two-circuit simplex windings, it follows that for four-pole windings we cannot have four conductors per slot.

It is with four-pole designs that this is most often found embarrassing, but the general rule applying to any number of poles is as follows:—

"In the ordinary two-circuit single winding, C is always such a number that the number of conductors per slot, and n the number of poles, cannot have a common factor greater than 2."

There are, however, several ways of evading this rule. These are illustrated by the diagrams in Figs. 190, 191, 192, and 193, each of which represents a two-circuit simplex winding with 40 face conductors. Were these arranged four per slot, we should have 10 slots, which is, of course, absurd for a four-pole machine. This small number has been taken merely in order to obtain simple diagrams. The principles illustrated are, of course, applicable to designs with large numbers of slots. In the winding of Fig. 190, the sequence of connections is clockwise until 39 conductors have been traversed; then, however, the direction of progression is reversed and the

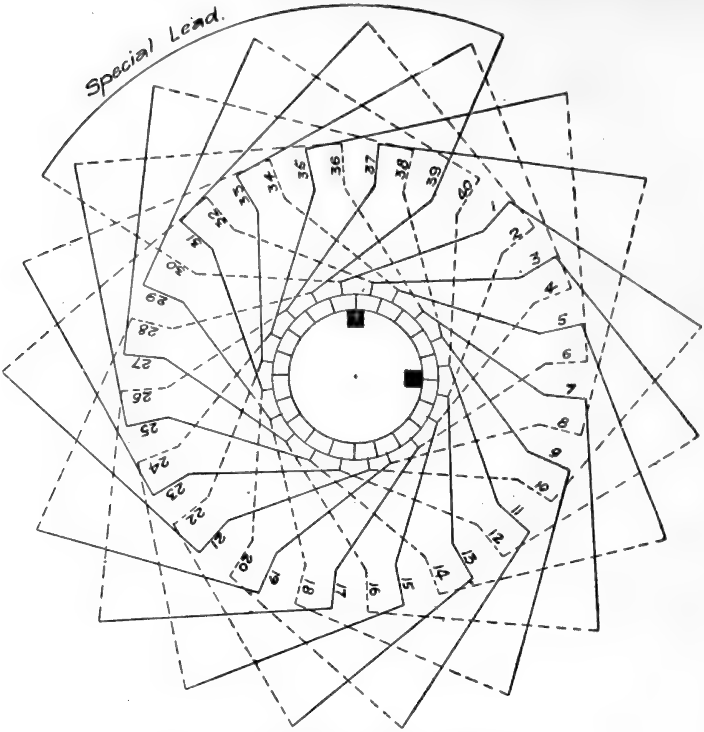


Fig. 190.—Special Two-circuit Winding.

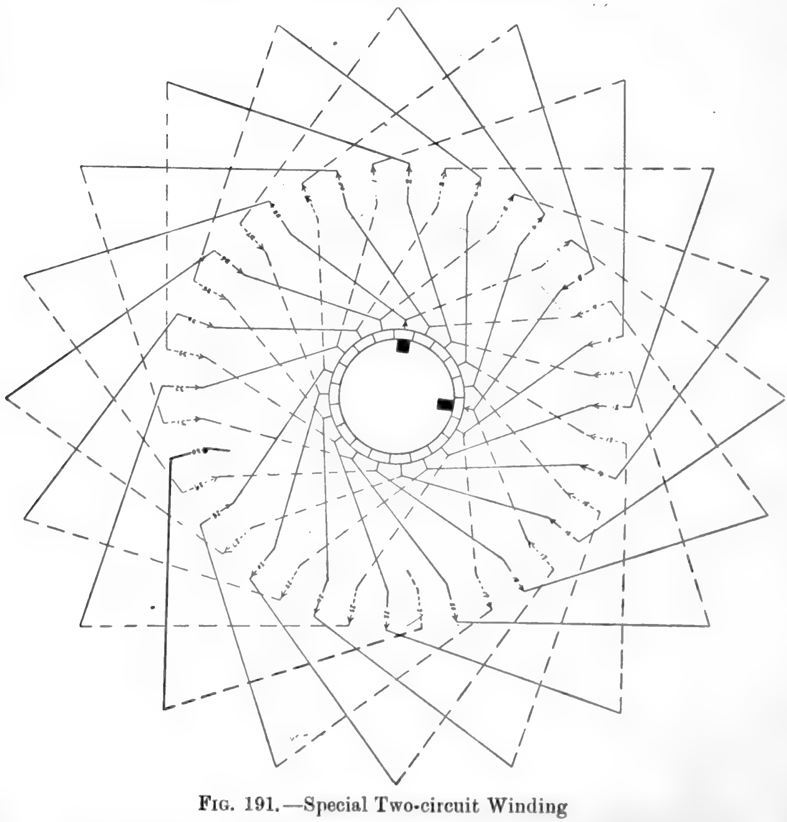


Fig. 191.—Special Two-circuit Winding

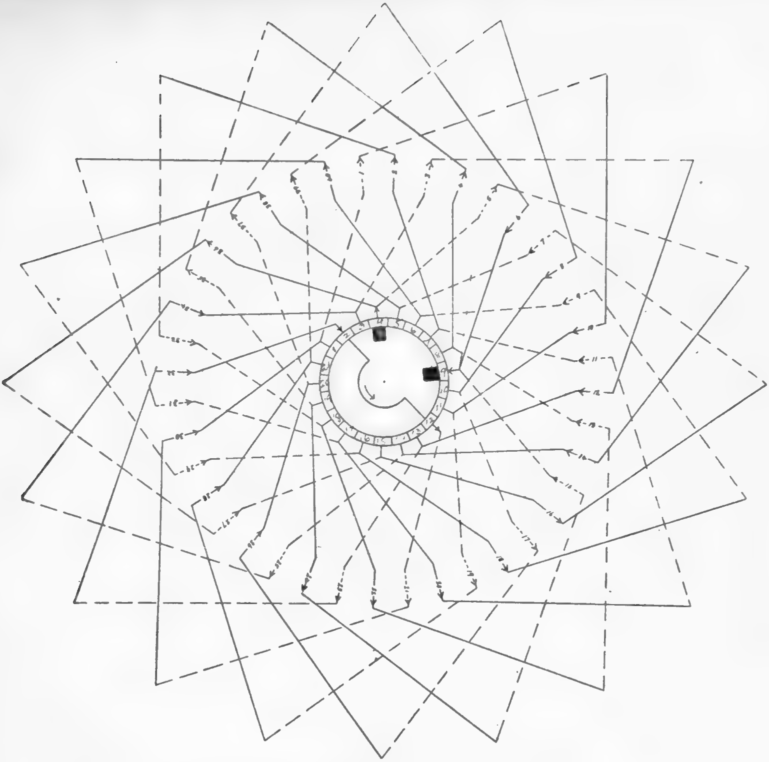


Fig. 192.—Special Two-circuit Winding.

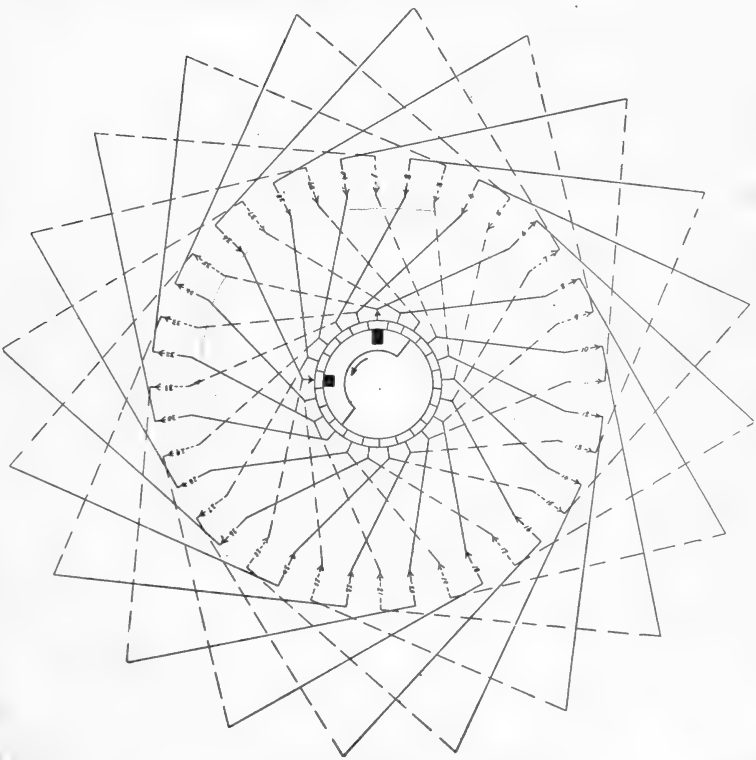
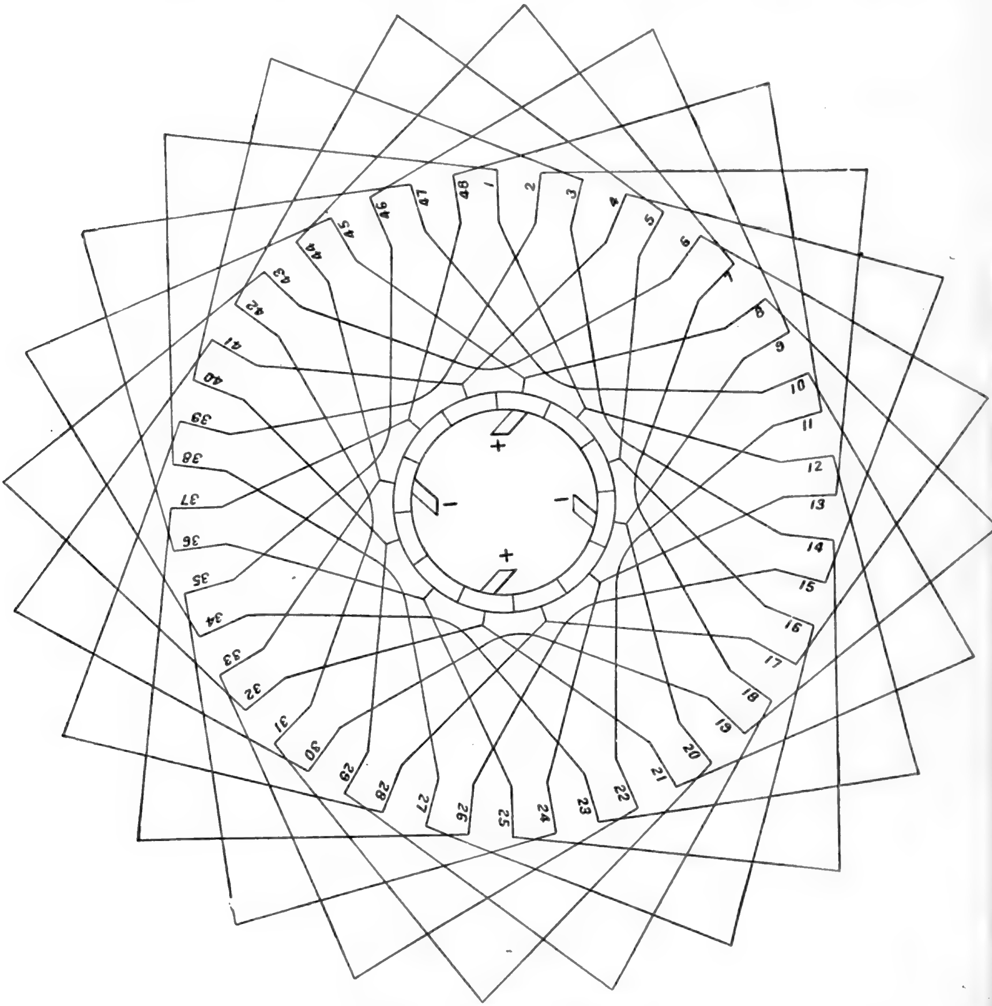


Fig. 193.—Special Two-circuit Winding.

last conductor is reached through a "special lead" as indicated in the diagram. There is an irregularity in the pitch. Starting from conductor No. 1, *yb* is **9**; thus 1 is connected with the back

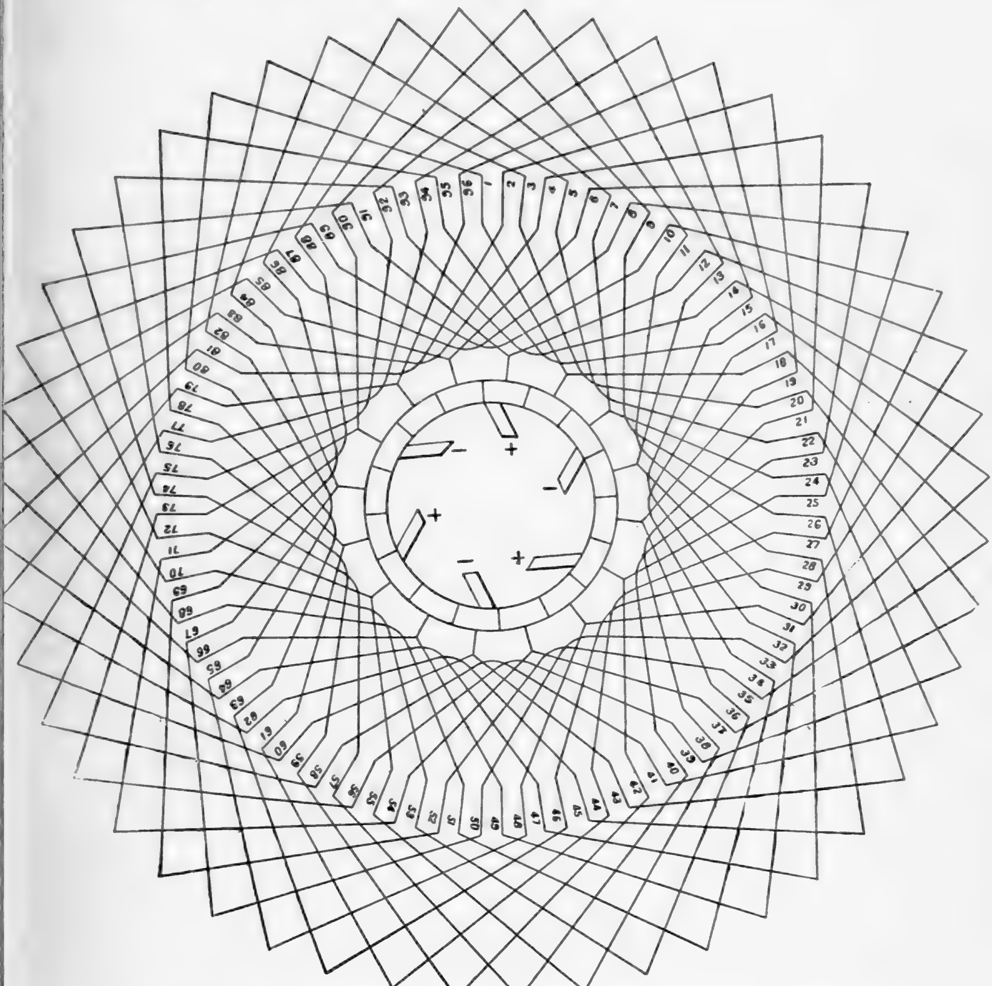


4-CIRCUIT SIMPLEX WINDING,

Derived from a 2-circuit, double winding of the formula $c=ny+2m$ ($48=4\times 11+2\times 2$) by omitting every other segment.

FIG. 194.

end to 10. *yf* is 11 in all cases. Thus 10 is connected over the front end to 21. But after traversing 21, it is connected over the back end to 32; *i.e.* *yb* is then 11. Thus, while *yf* is always 11, *yb* is alternately 9 and 11. This irregularity is undesirable for small pitches, as it would constitute a considerable percentage of the pitch; but for the large pitches associated with many



6-CIRCUIT SIMPLEX WINDING,

Derived from a 2-circuit, triple winding of the formula $c = ny + 2m$ ($96 = 6 \times 17 - 2 \times 3$) by leaving out every second and third segment.

FIG. 195.

designs the irregularity will have no serious consequences. It may constitute a greater percentage of the pitch, the lower the reactance voltage. The pitch of the "special lead" connection is $yb = 9$. Care must be taken in insulating the irregular conductors of such windings. In this case an even number (20) of commutator segments is employed.

In the winding illustrated in Fig. 191 there are only 19 commutator segments. In this case the turn comprising conductors 21 and 30 is not connected into the winding; indeed it is frequently not placed on the armature, the space being occupied by wooden strips. Thus to all intents and purposes Fig. 191 merely represents a winding with 38 conductors but with two places at which there is greater space between adjacent conductors than elsewhere. This winding gives better results the greater y and the lower the reactance voltage.

The type of winding illustrated in Figs. 192 and 193 involves the use of an extra segment. Thus we have 40 conductors and 21 segments. On the whole, it is a more attractive method than that shown in Fig. 190. Both methods have about the same degree of pitch irregularities.

Special Multiple-circuit Simplex Winding.

In Fig. 194 is shown a four-circuit simplex winding, which has the property of the two-circuit winding of having in the four branches a symmetrical distribution of the potential, even when the armature is eccentric in the field. This winding is derived from a two-circuit double winding by leaving out every alternate commutator connection. Because of the above-mentioned property, it should have a field of usefulness in motors of those ratings requiring several turns per segment, and it has the feature of superiority over the two-circuit winding that it ensures an equal division of the current between all sets of brushes of the same polarity. Very numerous similar windings may be derived. One other of this class is given in Fig. 195.

CHAPTER IX

ALTERNATING-CURRENT ARMATURE WINDING SYSTEMS

In the present chapter we shall study the question of winding schemes and diagrams for alternating-current armatures, following much the same plan employed in Chap. VIII. for continuous-current armature windings.

We shall regard the matter chiefly from the standpoint of the practical possibilities of the various windings considered in conjunction with their diagrams, and questions relating to the electrical and magnetic properties of the windings will not enter further than is necessary.

In the case of alternating-current windings, it is possible to represent by means of a diagram the aspects of the winding as it actually appears on the armature, with more precision than is the case with continuous-current diagrams. Thus, such questions as the shape of the coils and end connectors, their arrangement in layers and their location in the slots, may be intelligently represented in the diagrams by adhering to a few simple conventions, which will be explained in the course of this chapter.

When considering polyphase windings, we are able to distinguish between the windings of the various phases by the use of different colours for each phase, which is of great assistance in studying these windings from their diagrams.

Alternating-current windings fall at once into two broad classes:—

I. Open circuit windings.

II. Closed circuit windings.

The windings of Class I. are in most common use for alternators and induction motors.

The term "open circuit" signifies that the winding (or more precisely the winding of each phase) consists of a continuous path through the conductors which terminates at two ends—the terminals. So long as the terminals are not connected to any external closed circuit, the armature circuit remains "open."

The windings of Class II. find their application frequently in wound rotors for induction motors, and always in rotary converter armatures (which are dealt with in the latter part of this chapter). These windings consist of a continuous path through the conductors, which re-enters on itself, thus constituting a "closed circuit." They are carried out, and follow practically the same laws, as continuous-current windings, the difference being that instead of the winding being connected to the commutator segments at a large number of points, it is tapped at a few suitable points and connected to the slip-rings for the terminals of the phases.

In general, any of the continuous-current armature windings may be employed for alternating-current work, but the special considerations leading to the use of alternating currents, generally make it necessary to abandon the styles of winding best suited to continuous-current work, and to use windings specially adapted to the conditions of alternating-current practice.

Attention should be called to the fact that all the re-entrant (or closed circuit) continuous-current windings must necessarily be two-circuit or multiple-circuit windings, while alternating-current armatures may, and generally do, have one-circuit windings, *i.e.* one circuit per phase. From this it follows that any continuous-current winding may be used for alternating-current work, but an alternating-current winding cannot generally be used for continuous-current work; in other words, the windings of alternating-current armatures are essentially non-re-entrant (*i.e.* not closed circuit) windings. Re-entrant, *i.e.* closed, windings are, however, the only windings which are applicable to alternating-continuous-current commutating machines.

We shall consider Classes I. and II. separately, and as practically all alternating-current generator armature windings are of Class I., the greater part of this chapter is given up to the consideration of this class.

I.—OPEN CIRCUIT WINDINGS.

SINGLE-PHASE WINDINGS.

We shall first deal with single-phase windings, and this will lead into polyphase windings, as by superimposing a number of single-phase windings on a given armature at regular and suitable intervals we obtain a polyphase winding. In a simple single-phase winding we must connect one conductor or group of conductors to a similarly situated conductor or group of conductors under the next adjacent pole of opposite polarity.

Let us consider the case of a 6-pole alternator, the poles of which are diagrammatically represented in Fig. 196. For primary consideration let us take one conductor situated under each pole, represented by the thick radial lines numbered 1 to 6. Now, if the armature revolves in the direction indicated by the circular arrow at the centre of the diagram, then the induced electromotive forces will be in the direction indicated by the arrow-heads on the thick lines representing the conductors. Now, we have to connect these conductors up in such a way that the electromotive forces in all the conductors act in the

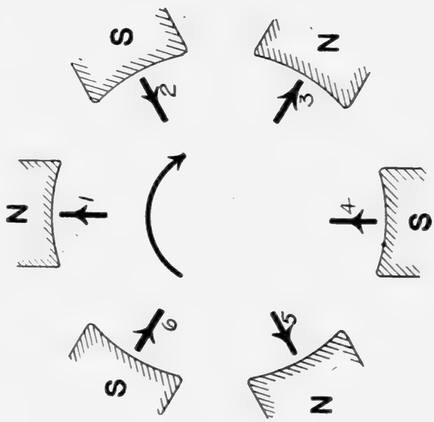


Fig. 196.

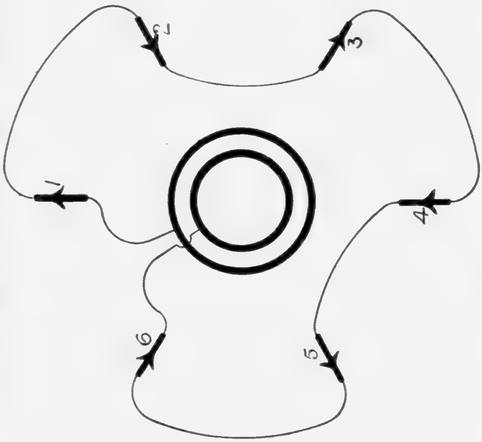


Fig. 197

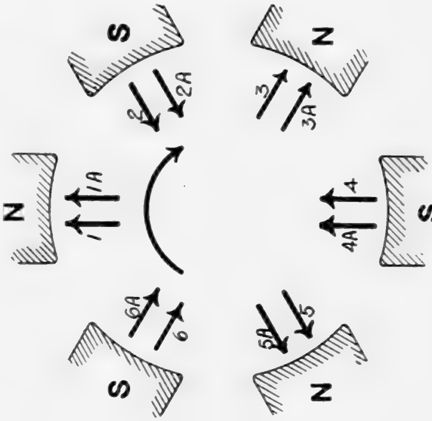


Fig. 198.

Development of Elementary Single-phase Winding.

same direction around the circuit. This has been done in Fig. 197, where it will be seen that the arrow-heads all point in the same direction when the winding is traversed from conductor No. 1 to No. 6.

The ends of conductors 1 and 6 are the terminals of the winding, and these we must connect to the machine terminals, or to the collector rings (or slip-rings) which are shown as two thick concentric circles in the centre of the diagram.

The diagram as it now stands represents a single-phase armature winding having one conductor per pole.

The external circuit is connected to the machine terminals. So long as the external circuit is not closed there is no completed path for the current from one collector ring to the other, and the circuit of the armature winding is open—*i.e.* it is an "open circuit" winding.

Now, suppose we have two conductors located under each pole in place of the one per pole in Figs. 196 and 197. These will stand as shown in Fig. 198, where they have been numbered 1, 1A, 2, 2A, etc.

If the direction of the rotation is as indicated, the induced electromotive forces will be in the relative directions shown in each of the conductors.

Now we will first connect up the conductors at the back end of the armature, that is, the outer end in the diagram, following the convention of Chap. VIII. We may do this in the manner shown in Fig. 199, which gives us a set of six elements, each element consisting of two conductors connected together at the back end of the armature.

We have now to connect these elements together in such a way that the arrow-heads (representing the direction of the induced electromotive forces) follow each other in the same direction round the circuit.

The simplest way of doing this and giving a symmetrical arrangement of the connections is in the manner shown in Fig. 200, *i.e.* by connecting at the front end of the armature, conductors 2 to 3, 4 to 5, and 6 to 1, which leaves us with 1A and 6A to connect to the terminals. These are connected each to a collector ring or stator terminal, as shown; and if the circuit be traced continuously, starting at one ring and terminating at the other, it will be seen that all the arrow-heads point in the same direction along the circuit, *i.e.* the electromotive forces in all the conductors act at any one instant in the same direction, and, consequently, are added to each other.

Now there is a second way in which we can connect up the conductors of Fig. 198, and still arrive at a simple and symmetrical grouping. If, instead of connecting at the back end conductor No. 1 to 6A, we connect it to No. 2A, and 3 to 4A instead of to 2A, also 5 to 6A instead of to 4A, we obtain the result shown in Fig. 201. Here we have a set of three elements, each consisting of four conductors connected in pairs at the back end of the armature. Fig. 201 should be compared with Fig. 199, directly above it.

If now we connect conductor 2A to 1A, 4A to 3A, and 6A to 5A, also 2 to 3 and 4 to 5, we arrive at the winding shown in Fig. 202, where the ends of conductors 1 and 6 remain as the terminals and are connected to the collector rings or other terminals.

Fig. 202 has been placed under Fig. 200, and these two windings, which are equivalent to one another electrically, should be compared.

To bring out more clearly the difference between these two types of windings, we have in Figs. 203 and 204 taken a 6-pole winding but with four conductors per pole.

Fig. 203 is drawn after the same manner as the winding in Fig. 200, and Fig. 204 after the manner of the winding in Fig. 202.

It will be first noted that in Fig. 203 the whole of the inner and outer circumference (corresponding to the front and back ends of the armature) is occupied by connectors between the various conductors; in Fig. 204, however, only half of the inner and outer circumference is occupied by these connectors.

This is clearly brought out by Figs. 205 and 206, which represent diagrammatically the back ends of the two armatures as they would actually appear with their windings in place.

There are a few other points which may be observed in connection with these two styles of winding.

Fig. 203, it will be seen, consists of six nearly similar elements connected together, while Fig. 204 consists of only three similar elements (compare with Figs. 199 and 201).

It will be convenient to designate the element of each winding a "coil," and Figs. 207 and 208 show respectively the coils of the windings of Figs. 203 and 204.

Now, since both these windings are 6-pole, we have in Fig. 203 one coil *per pole* or one *pole* per coil, and, in Fig. 204, one coil per *pair* of poles or one *pair* of poles per coil.

This brings us to our first broad division for alternating-current windings. Windings having *one* coil per *pole* we designate *whole-coiled* windings (the whole of the poles being subtended by coils).

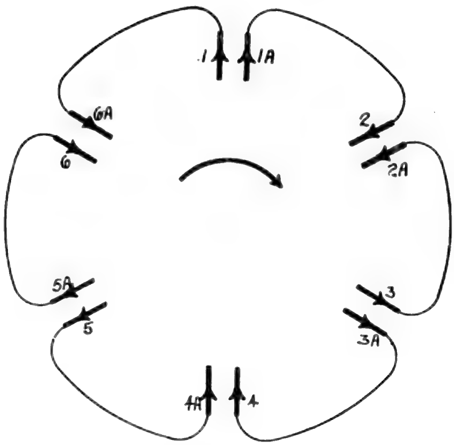


Fig. 199.

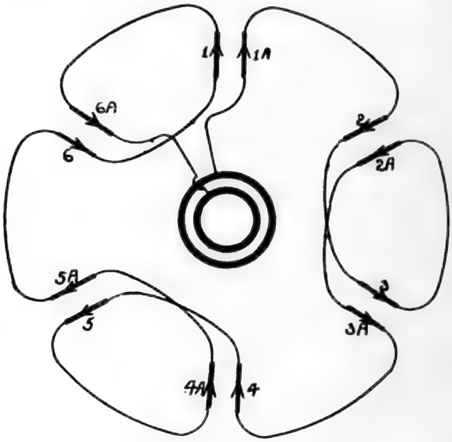


Fig. 200.

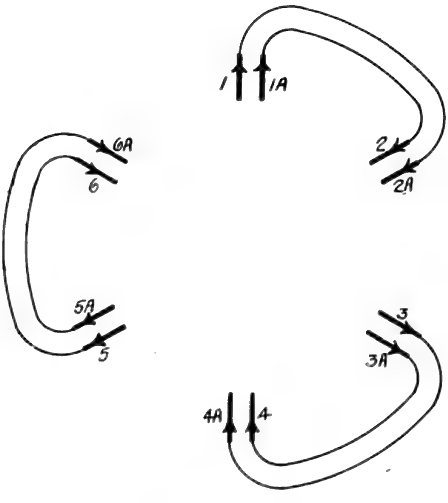


Fig. 201.

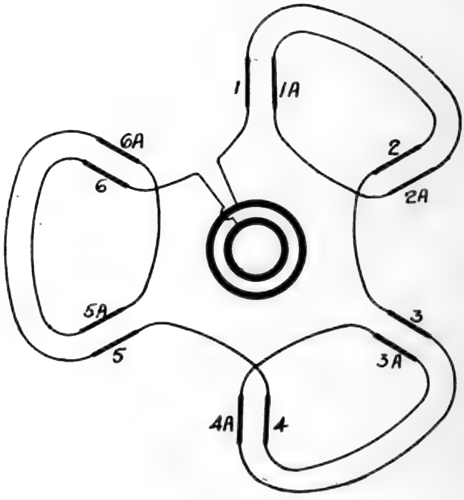


Fig. 202.

Single-phase Windings.
Upper row, "Whole-coiled" Windings. Lower row, "Half-coiled" Windings.

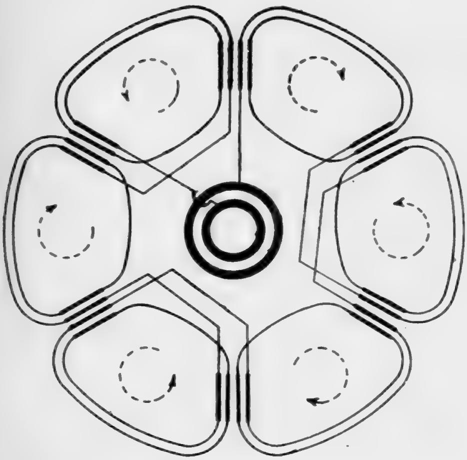


FIG. 203.

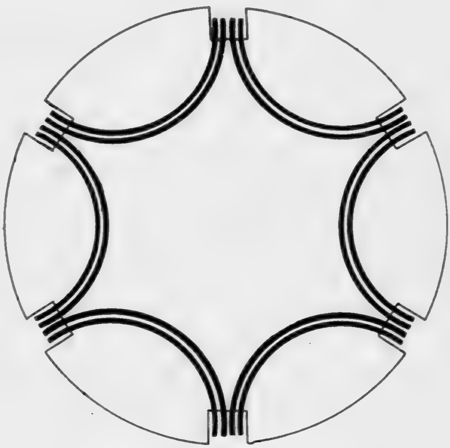


FIG. 205.

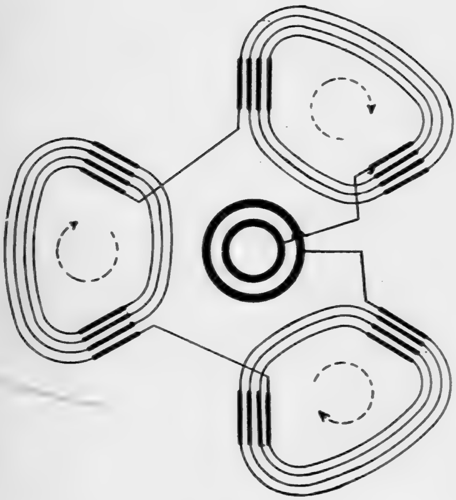


FIG. 204.

FIG. 206.

Single-phase Windings.

Upper row, "Whole-coiled" Windings. Lower row, "Half-coiled" Windings.

Windings having *one* coil per *pair of poles* we designate *half-coiled*[1] windings (only half of the total number of poles being subtended by coils).

The above relates to single-phase windings, but for polyphase windings the definitions will be: "whole-coiled" windings have *one coil per phase per pole*; "half-coiled" windings have *one coil per phase per pair of poles.*

The direction of the current circulation in the coils in each case is of interest as bearing on the connecting up of the coils to one another.

If we study the direction of the arrow-heads on the conductors, we see that in Fig. 203 the current circulates in a clockwise direction in three of the coils, and counter-clockwise in the alternate three coils.

The difference is, of course, due to the situation of the coils relative to the poles, as in Fig. 203 any two adjacent coils are situated under poles of opposite polarity, whereas in Fig. 204 they are under poles of the same polarity. The direction of the current circulation has been indicated by a dotted circular arrow at the centre of each coil.

If we wish to connect up the coils so that the current traverses the whole winding in the same direction, in the case of Fig. 203 we must connect the end of one coil to the end of its neighbour, or the beginning of one to the beginning of the next.

If we mark the left-hand end of all coils S (=start) and the right-hand end T (= terminate), then T of the first coil must be connected to T of the second one, and S of the second to S of the third, and so on. This is equivalent to reversing every alternate coil on its predecessor.

In Fig. 204, however, all the coils are connected up in the same way for the current to traverse the whole winding in the same direction.

Hence T of the first coil is connected to S of the second, T of the second to S of the third, and so on. This gives a less complicated arrangement of the connections between the coils than is the case in Fig. 203.

This is not a serious matter so far as single-phase windings are concerned; but when we come to polyphase windings, it is more important. As a matter of fact, the type of winding shown in

[1] The style of winding shown in Fig. 204 has been designated by Dr S. P. Thompson as "Hemitropic," literally signifying "half-turned" or "half-coiled." See *Polyphase Electric Currents*, S. P. Thompson, 2nd ed., 1900, p. 85.

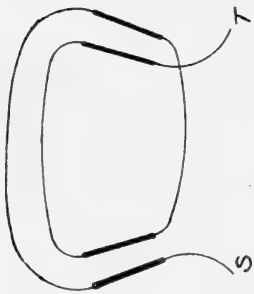


FIG. 207.—Typical Two-turn Coil.

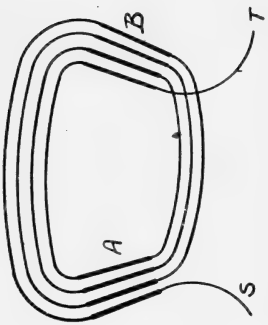


FIG. 208.—Typical Four-turn Coil.

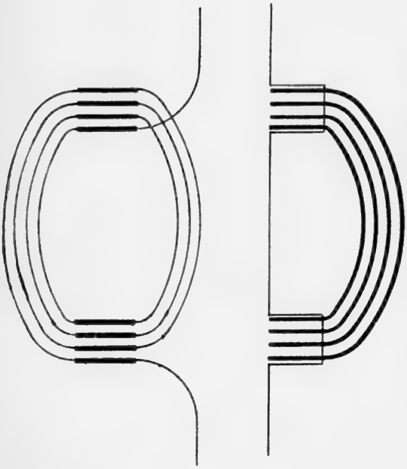


FIG. 209.—Concentrated Four-turn Coil.

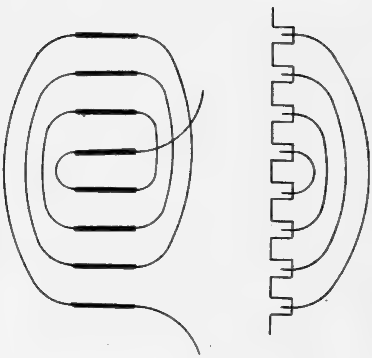


FIG. 210.—Thoroughly distributed Four-turn Coil.

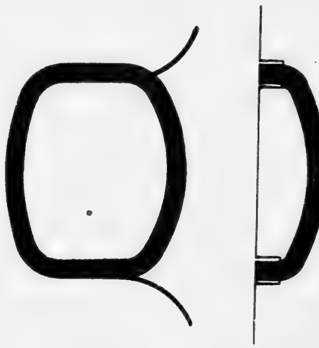


FIG. 211.—Single-coil Concentrated.

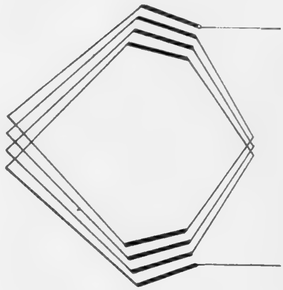


FIG. 215.—Four-turn "Lap-coil."

Fig. 204 is in far more common use for polyphase windings than that in Fig. 203, although for other reasons than the above (which will be dealt with when we come to consider polyphase windings).

Before leaving this batch of figures it is desirable to point out that, in all subsequent winding diagrams, we shall adhere to the style of coil in Fig. 208 in all the types of winding into which this coil enters.

This is, it will be seen, wound by commencing with the inside conductor of the right-hand group and spiralling outwards, taking in all the conductors successively, finishing with the outside conductor of the left-hand group.

It would have been possible to wind the coil in the reverse direction, commencing with the inside conductor of the left-hand group and finishing with the outside conductor of the right-hand group. The previous method is, however, the most usual, and is in fact easier to carry out in practice, and hence we shall adhere to it throughout.

So far, when considering single-phase windings, we have only considered the number of conductors in their capacity of making up a coil, and have not touched on their spacing out on the armature or their distribution or concentration relative to one another. Thus the conductors constituting a coil may be all concentrated in a single large slot, or they may be distributed in a small or large number of slots.

The two extreme cases are represented in Figs. 209 and 210, where we have taken for consideration a coil out of the winding in Fig. 204, consisting of four turns. In Fig. 209 the four turns are concentrated in two large slots, each one containing the conductors of each side of the coil. In Fig. 210 the four turns are distributed over eight small slots, resulting in one conductor per slot. The conductors on each of the coils are now spread over four slots.

We shall employ the terms "single-coil," "double-coil," "triple-coil," "quadruple-coil," etc., to designate whether the coil (as defined above) is divided into one, two, three, or four parts, each part occupying a single pair of slots. Thus the coil in Fig. 207 will be a "double-coil," consisting of two parts, and occupying two slots on each side of the coil. Similarly, the coil in Figs. 208 or 210 is a "quadruple-coil," while that in Figs. 209 and 211 is a "single-coil." It is desirable not to employ the terms "uni-slot," "two-slot," "three-slot," etc., to define the distribution of the coil, but to use these terms only to indicate the number of slots per pole per phase. Thus such a term as "four-slot" prefixed to the title of a winding only signifies that it has four slots per pole per phase. Such a winding is not necessarily "quadruple-coil," as we shall see. The broad division between windings, as regards their distribution, is "single-coil" and "multi-coil." The latter describes all windings where the coil is distributed over a number of slots greater than unity.

The "single-coil" winding is often used for single-phase alternators, as this permits of the most effective disposition of the armature conductors as regards generation of electromotive force. If more slots or coils are used, or, in the case of face windings, if the conductors are more evenly distributed over the face of the armature, the electromotive forces generated in the various conductors are in different phases, and the total electromotive force is less than the algebraic sum of the effective electromotive forces induced in each conductor. But, on the other hand, the subdivision of the conductor in several slots or angular positions per pole, or, in the case of face windings, their more uniform distribution over the peripheral surface, decreases the self-induction of the windings with its attendant disadvantages. It also utilises more completely the available space, and tends to bring about a better distribution of the necessary heating of core and conductors.

The advantage of the "single-coil" winding is that it gives the maximum obtainable total electromotive force for a given number of conductors, whereas the electromotive force obtained from the same number of conductors but distributed or arranged as a "multi-coil" winding is considerably less. The armature reactions are, however, for a given number of conductors and a given current—greatest when these conductors are arranged as a single-coil grouping, which is an undesirable feature.

While the single-coil type is used considerably for single-phase armatures, the windings for polyphase armatures are almost always multi-coil, having a number of slots per pole per phase varying from two up to as high as ten in turbo-alternators, where the high speed renders only few poles necessary.

In graphically representing single-coil windings it is not convenient to draw out a number of conductors concentrated together, and it is customary to represent a single concentrated coil of many turns by a thick line with a thin line at its beginning and end, representing the terminals.

Thus Fig. 211 shows graphically a coil of a single-coil winding, which may represent a coil of any number of turns. This will be employed to represent the coils in any subsequent single-coil winding diagrams, and the number of turns per coil can be specified in any particular case.

Fig. 212[1] shows a 6-pole single-coil winding with the coils drawn in this way. Let us suppose that each coil consists of four complete turns, then we should have eight conductors located in each slot. If now these eight conductors were spread out over eight slots instead of being concentrated in a single slot, we should obtain the winding shown in Fig. 213. This is an example of a thoroughly distributed single-phase winding, the conductors being located in slots distributed over the whole of the armature periphery at equal intervals. This is now a "quadruple-coil" winding, but it is also an eight-slot winding, as there are eight slots per pole.

This arrangement of the conductors gives the minimum value for the total electromotive force, whereas the single-coil winding of Fig. 212 would give the maximum value.

It is possible to arrange the winding in other ways between these two extreme cases, and Fig. 214 shows one such intermediate arrangement. This winding is still an eight-slot winding, but the slots are concentrated together in groups, so that they occupy two-thirds of the complete periphery of the armature.

The comparison of the windings in Figs. 212, 213, and 214 leads up to the matter of spread of the winding, on which the total electromotive force depends.

The spread of the winding is defined as the percentage of the periphery which is occupied by windings. Thus the spread of the winding in Fig. 212 would be only about 10 per cent., whereas in Fig. 213 it is 100 per cent.—*i.e.* in the latter case the slots containing the winding are uniformly spread over the whole of the periphery. In Fig. 214 it will be seen that the slots are only distributed over about two-thirds of the periphery, and the spread of the winding is here 66 per cent.

In the case of the whole-coiled windings (having *one* coil *per pole*) the spread is the percentage of the pole pitch which a single coil occupies on *both* sides. Thus in Fig. 214 each side of the coil occupies one-third of the pole pitch, and the two sides together 66 per cent., which is the percentage spread. In the case of the "half-coiled" windings (having *one* coil *per pole pair*) the spread is the percentage of the pole pitch occupied by a single coil on *one* side.

[1] The connections between the coils in Fig. 212 and in Figs. 213 and 214 will be clear from what has been said above in connection with Figs. 203 and 204.

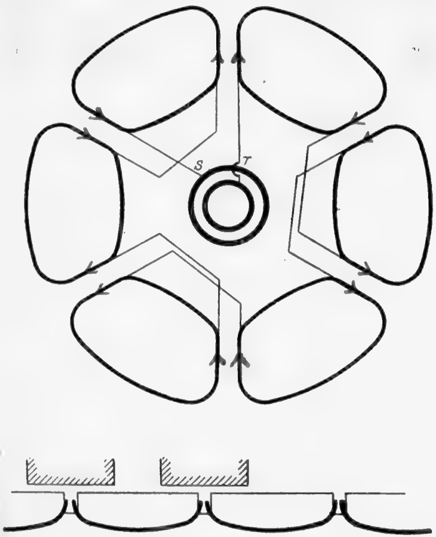


FIG. 212.—Concentrated.

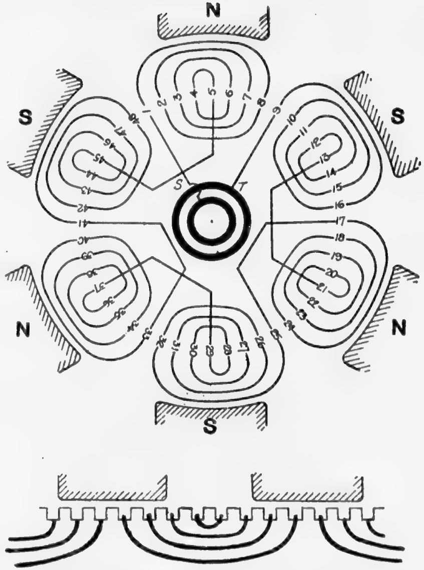


FIG. 213.—Thoroughly distributed.

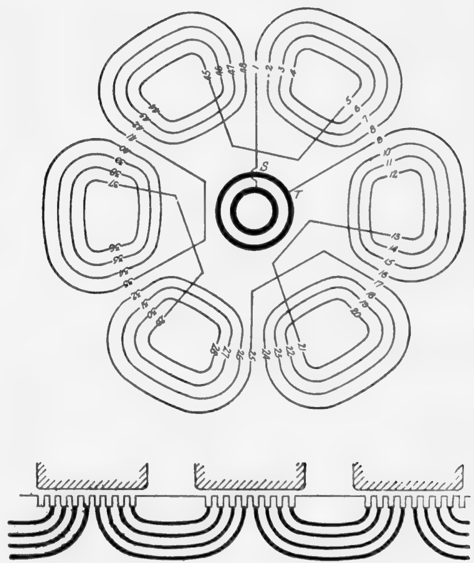


FIG. 214.—Semi-distributed.

Single-phase Windings.

Thus if the winding of Fig. 214 were constructed with three coils instead of six, *i.e.* with one coil per pair of poles (as in Fig. 204), each coil would cover eight slots on each side, which is two-thirds of the pole pitch, and the spread would still be 66 per cent. In both cases the percentage of the total periphery occupied by windings, which is the definition of the spread, is 66 per cent., which is correct, as the windings are electrically identical. The number of slots per pole is in both cases eight, and were the whole of the periphery occupied by slots, there would be twelve slots per pole. The spread is then the ratio of the number of slots occupied by windings per pole to the number of slots per pole. In polyphase windings the spread of each phase is the number of slots per pole *per phase* divided by the number of slots per pole.

The above will suffice to give a broad idea of the subject of single-phase windings in general. We have now established two sets of fundamental terms: (1) "Whole-coiled" and "half-coiled"; (2) "single-coil" and "multi-coil."

However, thus far we have only considered windings having *spiral coils*, similar to the element shown in Fig. 208.

There is another way of arranging the coil and still obtaining an open-circuit winding equivalent to any of the above.

In this type of winding we designate the element a *lap coil*, and its nature and difference from the *spiral coil* will be apparent from Fig. 215, p. 171, which should be compared with Fig. 208.

The lap coil lends itself better to coil form winding than the spiral coil, as in the former the pitch of the conductors is a constant; for instance, in Fig. 215 the distance between any conductor in group A and the one to which it is connected in group B is the same as for any other pair, and thus at both back and front of the armature the end portions of the coils are identical in shape and size, and can be made all on one former.

In the spiral coil (Fig. 208), however, this is not practicable, as the pitch is different for each conductor in the group. The spiral coil is used in connection with semi-closed or entirely closed slots, and the winding is generally done by hand.

Fig. 216 shows the 6-pole winding of Fig. 214 carried out with lap coils.

Fig. 217 is a photo of a similar winding, but for a much greater number of poles than six. The spread of this winding is 100 per cent., and each coil is distributed over twelve slots, which cover a whole pole pitch. This winding has twelve slots per pole and

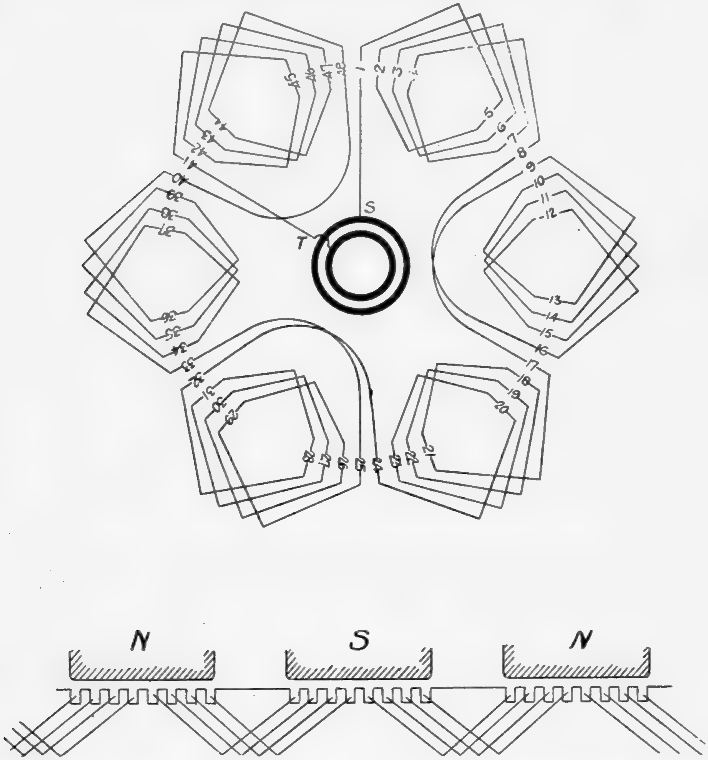


Fig. 216.—Single-phase Semi-distributed Whole-coiled Lap Winding.

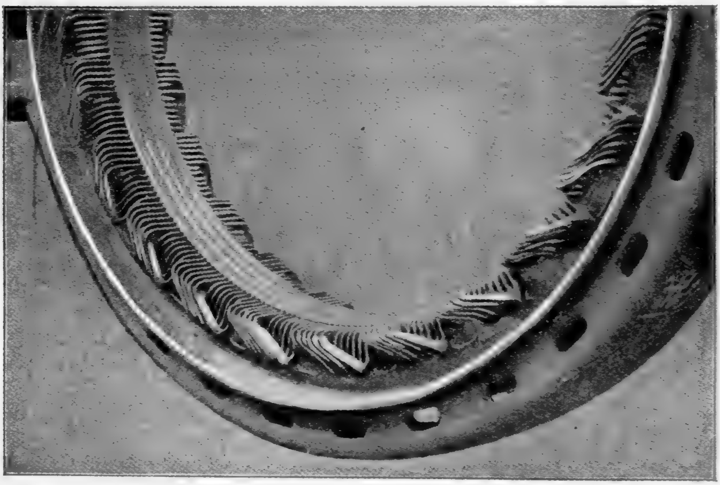


Fig. 217.—Single-phase Distributed Lap Winding.

is thus a twelve-slot winding. Adhering to the denomination described above, its title would be a twelve-slot, single phase, whole-coiled, sextuple coil, lap winding. This title wholly describes the winding with the exception of the number of conductors per slot, which should be stated separately.

The bent shaping of the ends of the coils, to make them lie up together, will be noted.

Polyphase Windings.

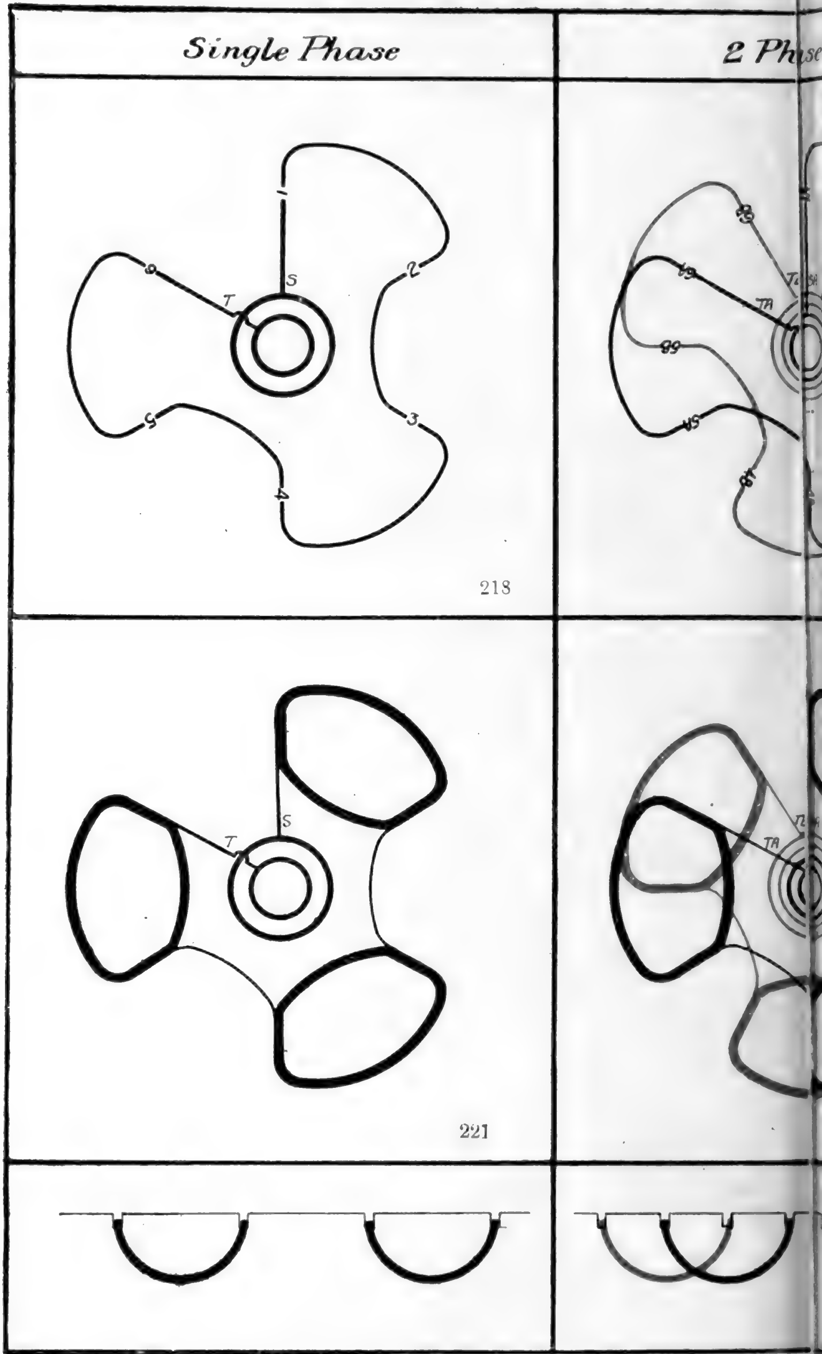
As was stated at a previous point, any polyphase winding is derivable from a single-phase winding by superimposing on the armature a number of separate single-phase windings at regular and suitable intervals. Thus, if we take the elementary single-phase winding given in Fig. 197 (reproduced in Fig. 218) and superimpose another similar single-phase winding, but displaced from the original, as shown in Fig. 219, we obtain an elementary two-phase winding (or quarter-phase, as it is sometimes, and more correctly, called).

We have in Fig. 219 distinguished the second phase by colouring it red, and also by suffixing the letter B after the number on each conductor, in distinction from A for the first phase.

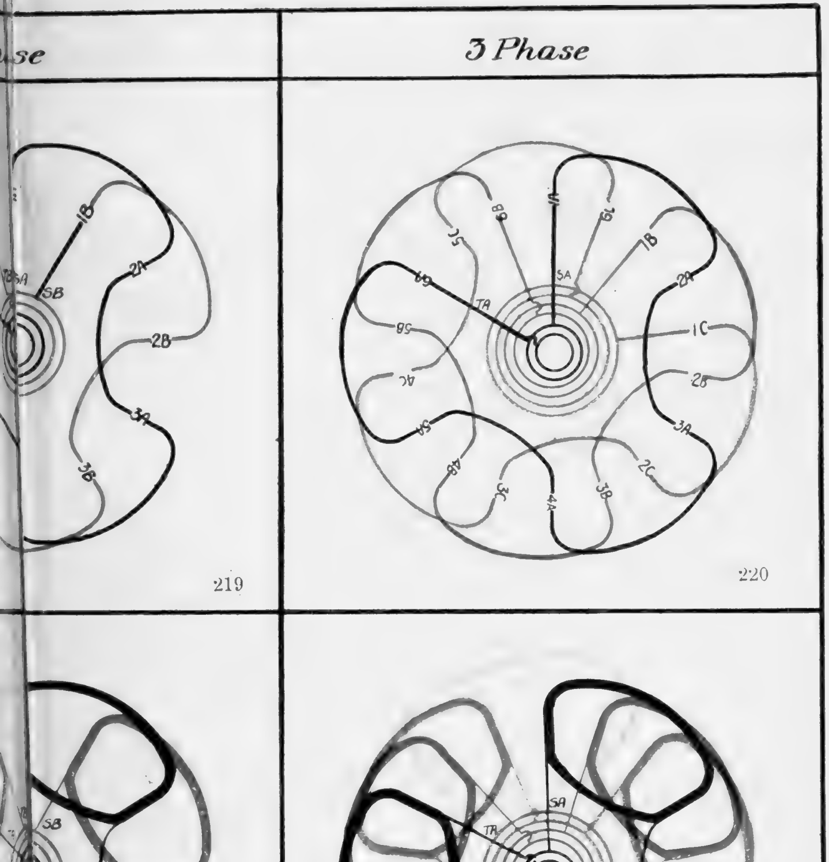
It will be noted that conductor 1A is situated midway between conductors 1 and 2; and as the distance between the conductors 1 and 2 is equivalent to one pole pitch, it follows that the second phase is displaced from the first by one-half of the pole pitch. This displacement is one quarter of a double pole pitch, which corresponds to a complete period in the E.M.F. wave; hence the more correct designation is "quarter-phase" rather than "two-phase."

If we wish to obtain a three-phase winding, we must insert two extra phases within the double pole pitch. This has been done in Fig. 220, where we have now the three phases marked A, B, and C. The conductors 1B and 1C are evenly disposed between conductors 1A and 3A of phase A, and each is displaced from the other by one-third of a double pole pitch. Thus the displacement of the phases is one-third of the period.

The windings shown in Figs. 221, 222, and 223 are closely related to the windings of Figs. 218, 219, and 220, and they have been drawn immediately under them for the purpose of giving a clear view of the elementary polyphase windings. The difference between the upper and lower groups of windings is, that while in



FIGS. 218-223.—Derivation of Single-phase, T



...hase, and Three-phase Half-coiled Windings.

Fig. **223,** *see Erratum Note, p.* 188.

Figs. 218, 219, and 220 we have only one conductor situated under each pole, in Figs. 221, 222, and 223 we have a number of conductors in a concentrated group under each pole in place of each single conductor in the former case.

Hence in Fig. 221 we have a set of three coils, each consisting of a number of turns, connected together and represented by a thick line, as in Fig. 211.

Similarly, in Fig. 222 we have two sets of coils—the red and the black—each set of three connected together as in Fig. 221, and each constituting one of the two phases. Also in Fig. 223 we have three sets—black, red, and blue—each set constituting one of the three phases A, B, and C.

We shall, as in the single-phase windings, mark the two terminals of each phase S and T; but to distinguish between the phases, the letter of each phase is suffixed—thus S_A and T_A indicate the terminals of phase A, and so on.

In Figs. 219–223 we have shown one separate pair of collector rings connected to the terminals of each phase. In practice it is very rare to provide two slip-rings for each phase, or in the case of stationary armatures, two lines leaving the machine terminals for each phase, as polyphase windings lend themselves, by virtue of the properties of polyphase currents, to convenient interconnection of the phases, so that some of the rings or terminals may be dispensed with.

Three-phase armatures are almost invariably interconnected, so that instead of six terminals and six lines constituting three independent phases, there are only three. The two methods of connecting three-phase windings are the *star grouping* and the *mesh grouping*. These names are suggested by the appearance of the diagrams illustrating them shown in Figs. 224, A and B.

These two arrangements are also commonly known as Y connected and Δ (Delta) connected, which designations are more suggestive.

In Figs. A and B, the coloured limbs represent each the windings of a phase with its terminals marked S and T, as in the case of the winding diagrams.

For the Y grouping, the three similar terminals of the phases, for instance T_A, T_B, T_C, are connected together, and the other three similar terminals, S_A, S_B, S_C, constitute the machine terminals which are connected to the line. The junction of T_A, T_B, T_C, is known as the mid-point or common junction of the system.

For the Δ grouping, the ends of the three phases are connected up into a closed circuit (or mesh)—the end of one (T_A) to the beginning of the next (S_B). The three junctions between the phases are connected to the machine terminals.

If, when any winding is completed, the terminals of the phases are lettered S and T at their beginning and end, then to connect up for Y or Δ, one has only to remember the following:—

Y *Grouping.*—Connect the beginnings (S) of the three phases to the three machine terminals; and connect the ends (T) of the three phases together, forming the mid-point—*i.e.*

Connect phase	A	between	terminal	I.	and	mid-point.
„ „	B	„	„	II.	„	„
„ „	C	„	„	III.	„	„

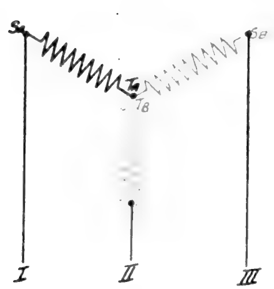


Fig. 224, A.

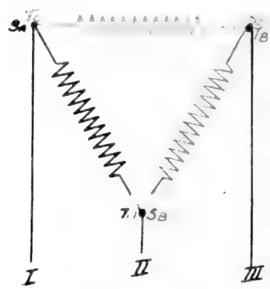


Fig. 224, B.

Y and Δ Three-phase Groupings.

Δ *Grouping.*—Connect the beginnings (S) of the three phases to the machine terminals and also to the ends (T) of the preceding phases—*i.e.*

Connect phase	A	between	terminals	I.	and	II.
„ „	B	„	„	II.	„	III.
„ „	C	„	„	III.	„	I.

The appropriateness of these connections will be seen from the following considerations relating to the diagrams in Fig. 225.

One complete cycle is passed through by any armature conductor while passing from a certain point opposite one pole piece, say the middle of the north pole, to the corresponding point opposite the next pole piece of the same polarity. This angular distance is 360 electrical degrees, independent of the number of poles of the machine. Now, a three-phase armature winding is merely three single-phase windings laid on the same armature, the conductors of the three windings, however, being located 120 degrees (one-third of a cycle) behind each other. Any conductor of one winding is, therefore, at any instant, in a different phase from that of the conductors of the other windings. Thus, in the position

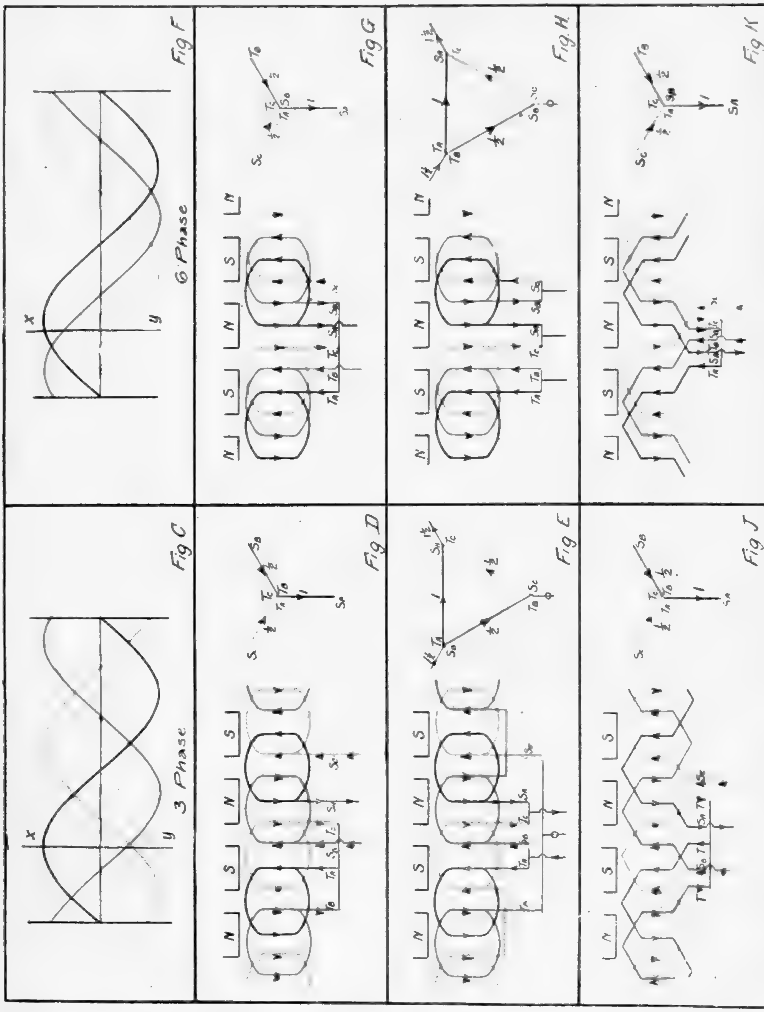


FIG. 225.—Y and Δ Connections for Three-phase Windings.

represented in Fig. D in Fig. 225 the conductors represented by black lines are directly opposite the middle of the pole pieces, the blue line conductors are located 120 degrees behind them, and the red conductors are 120 degrees behind the blue conductors and 240 degrees behind the black conductors.

Now it follows, from the relative positions of the conductors of the three phases, that the electromotive forces generated in the three windings are 120 degrees behind each other; and if they are sine waves they may be represented, as in Fig. C, by three sine curves displaced 120 behind each other and coloured according to the phases.

If the three circuits are equally loaded, these curves may also be considered to represent the corresponding instantaneous values of the current.

It will be noted that at every instant the algebraic sum of the three currents is zero.

For instance, at the time demarcated by the line *xy* in Fig. C, which corresponds to the positions of the conductors in Fig. D, the current in the black conductors has its maximum value, and the current in each of the red and blue conductors has a value of just one-half of the maximum and in an opposite direction with regard to the black phase. Hence at this instant the current flowing out of the black conductors could be returned one-half through each of the red and blue conductors. This would be the case when the winding is Y-connected, as will be seen from Fig. D, where, at the instant, the current in the black phase is flowing away from the neutral point, while in the red and blue phases it is flowing to the neutral point.

A safe and easily understood way of connecting the three windings correctly to the three collector rings and the common connection is to consider that the winding whose conductors occupy the position in the middle of the pole piece is carrying the maximum current, and to indicate its direction on the winding diagram by an arrow. The currents at the same instant in the conductors immediately next to it on the right and left are in the same direction, and should be so marked by arrow-heads. Now, from the curves given in Fig. C above, it will be seen that where one curve has a maximum value the other two have a value half as great, and in the opposite direction. Therefore, if we consider that the current in the winding occupying the position at the middle of the pole face is flowing away from the common connection, then the currents in the other two windings, which are each of half the magnitude of the former, must both be flowing into the common connection. We must therefore join those ends of the three windings to the common connection, which will bring about this condition at this instant. The other three ends of the winding are connected to the three lines.

In Fig. D we have lettered the terminals S and T according to our convention, and have connected up the winding Y fashion by aid of the arrow-heads on the conductors. We have the three ends T_A, T_B, T_C connected together at the neutral point, and the three beginnings S_A, S_B, S_C connected to the lines, which is quite in accordance with the rule given on p. 179.

In connecting up the separate windings for a "delta" (Δ) connection, it is most convenient to examine the conditions at the instant when the conductors of one phase are opposite the middle of a pole piece. Then assume these conductors to be carrying the maximum current, which is illustrated in Fig. E by the arrow-heads on the black conductors. The other two windings have in them at the same instant currents of only one-half this magnitude. The condition of affairs in line and in winding is, for the instant, as represented in the Δ diagram on the right hand of Fig. E, and the currents in the windings are as indicated by the arrows in the winding on the left hand of Fig. E.

It will be seen that the connections agree with those given in Fig. B, according to the rule on p. 179.

Figs. D and E show two coils of each phase and four poles, but the conditions are exactly the same if the total number of coils are taken in, as for terminals S_A, S_B, S_C we have taken the beginnings of the first coil of each phase connected in, and for terminals T_A, T_B, T_C we have taken the ends of the last coils connected in.

The group of coils in Figs. D and E corresponds to the winding of Fig. 223 and to all of the three-phase two-range windings given subsequently.

It is safer, in connecting up any three-phase winding, to determine the connections from the directions of the induced currents. In some windings, which are strictly six-phase windings, it is necessary to reverse one phase.

Thus in the winding of Fig. G (which is the same as Fig. 223), when Y-connected by consideration of the arrow-heads on the conductors, the red phase is reversed and S_B instead of T_B connected to the neutral point.

The winding is really a six-phase winding, and the relative currents are as shown by the curves of Fig. F. To convert Fig. F into the true three-phase arrangement of Fig. C the red curve must be reversed, which is effected by reversing the connections of the red phase.

The general distinction between the two cases is summarised by the following :—

If the three conductors from which similar terminals are taken (as in S_A, S_B, S_C) lie evenly distributed within *one pole pitch*, one phase must be reversed.

If these three conductors lie evenly in the region of a pair of poles, *i.e.* within *a double pole pitch*, the phases are connected up in order, as in Fig. 224, B.

This distinction is brought out also by Figs. J and K, which are respectively really three- and six-phase, both Y-connected. These windings correspond to the wave windings of Figs. 269 and 271.

The Y connection is most commonly used for generators. This is because the pressure per phase in the Y grouping is only 0·577 $\left(=\frac{1}{\sqrt{3}}\right)$ of the terminal pressure; for instance, if the generator is required to give 10,000 volts at the terminals—*e.g.* between terminals I. and II., Fig. A—then each phase will only have to generate 5770 volts; and this will be the pressure between each terminal and the mid-point, as, for instance, between S_A and T_A. The advantage in this is that the neutral point may be grounded and the slot insulation need only be of such proportions as are allowed for 5770 volts, which is much less than for 10,000 volts.

In the Δ connection, if we had 10,000 volts at the terminals as between I. and II., the volts per phase will also be 10,000 as between S_A and T_A, and the machine must be insulated accordingly.

As most alternators are for very high voltages, this point becomes of importance; but with low-voltage machines, as the ordinary induction motor, it is not serious. For other reasons also, relative to the size of the wires and their arrangement in the slots, which do not generally apply to generators, the Δ connection is sometimes preferable for induction motors.

Two-phase windings are not so often interconnected, and the ordinary case of a two-phase winding with independent phases and four lines is shown, diagrammatically, in Fig. 226, A.

The other common grouping for two-phase is a three-line grouping shown in Fig. 226, B. Here the ends of the two phases are connected together and to a common line, and the beginnings of the phases to the other two lines. This connection is sometimes known as two-phase with common return.

We shall not deal with the connections of four-phase and six-phase windings, as such are not in common use; the latter, however, will be referred to in connection with rotary converter windings at a later part of this chapter.

In connection with the winding diagrams already given, and given subsequently, it is desirable to point out that it is immaterial which of the several coils of each phase have their ends form the terminals of the phases so long as they are all connected up successively round the armature. For example, in Fig. 219 we started with conductor 1A and connected up phase A successively, making conductors 1A and 6A the terminal connections.

Similarly, for phase B we had conductors 1B and 6B. It would have been quite in order if we had taken, say, 3B and 2B, or 5B and 4B, instead of 1B and 6B, or similarly for phase A. It does not matter from what points the terminals are brought out, so long as the coils of one phase are all connected up in their proper order.

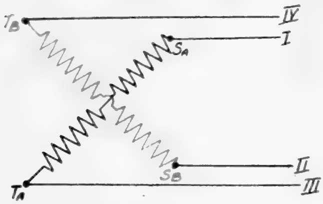


FIG. 226, A.

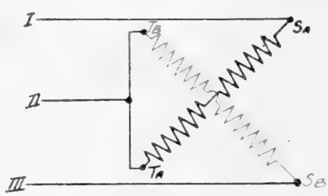


FIG. 226, B.

Two-phase Groupings.

As, however, in the actual armature it is desirable to have the terminals all coming out at about the same spot on the armature (near the machine terminals), we shall adopt this plan in all our diagrams and bring out the terminals of the phases as near together as possible.

It will have been noticed that the windings in Figs. 221, 222, and 223 are all of the half-coiled variety (see p. 170)—*i.e.* there is *one* coil for each phase under each *pair* of poles. Thus in Fig. 223 the total number of coils is nine, and as there are three phases, there are $9/3=3$ coils per phase. The number of poles is, however, six, which is double the number of coils per phase.

Suppose, now, instead of connecting the whole of the conductors forming the group 1A (in Fig. 222) to the group 2A, we only connected *half* of them to *half* of the conductors in group 2A; then it is quite permissible to connect half of 1A in an opposite direction back to half of the group 6A in a similar fashion to Fig. 212. By so treating each group, 1A, 2A, 3A, etc., we obtain the winding shown in Fig. 227, which is the two-phase winding corresponding to the single-phase winding of Fig. 212, as each phase is identical therewith.

It will not be difficult to see that, by dealing with the three-phase winding of Fig. 223 in like manner, we obtain the winding of Fig. 228.

In both Figs. 227 and 228 every pole is subtended by one coil

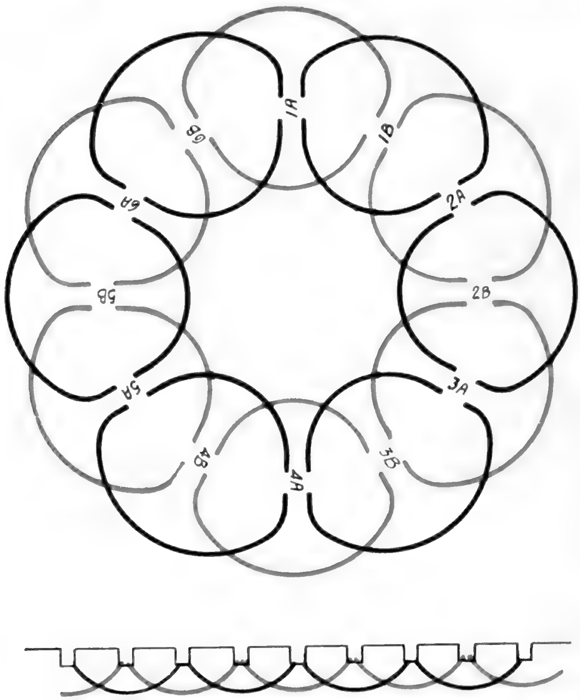


FIG. 227.—Two-phase Whole-coiled Winding (one coil per phase per pole).

of each phase, *i.e.* the number of coils per phase equals the number of poles, and these two windings are both whole-coiled windings.

Reverting again to the half-coiled three-phase windings of Fig. 223, there is another way of grouping the coils of the several phases with respect to one another, the winding still remaining half coiled. This grouping is shown in Fig. 229, and it is strictly a six-phase grouping, as will be seen in Fig. 225, G and H.

An inspection of Fig. 229 will show that the winding consists of three groups of coils—each group consisting of three coils, one of each phase. For instance, the first group comprises all the conductors from 1A to 2C (inclusive). The armature, when wound, could be divided into three sections, each section containing one of these groups of coils, without interfering with the coils themselves. If three radial lines are drawn between conductors 6c and 1A, 2c and 3A, 4c and 5A, the armature can be divided at the points marked by these lines, it being only necessary to break the connection between the coils. This is a good point to realise, especially with very large armatures, which, if wound

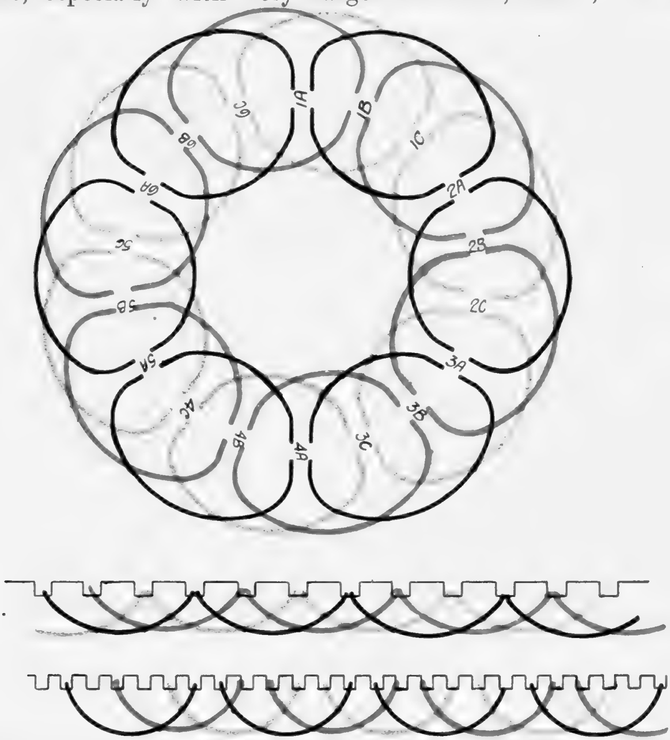


Fig. 228.—Three-phase Whole-coiled Winding (one coil per phase per pole).

in this way, can be built and transported in several sections, each fully wound. The style of winding has, however, several disadvantages, a prominent one of which is that the crossings of the end portions of the coils do not permit of a simple arrangement. The end view underneath Fig. 229 shows that one coil of each phase crosses both of the other phases.

The coils would have to be laid up in three ranges at the ends of the armature in either of the ways shown in Fig. 230—*e*, *f*, and *g*. We shall have more to say on the number of ranges for various windings, and also on the matter of dividing the armature into sections just referred to, when we come to study the photographs of various types of winding with their diagrams, later on in this chapter.

In Fig. 223 the coils are no longer collected in groups of three, as in Fig. 229, and owing to this feature the armature cannot be divided into sections without dismembering several of the coils.

This winding is, however, capable of being laid up in two ranges in the manner shown in Figs. 230*c* and 230*d*.

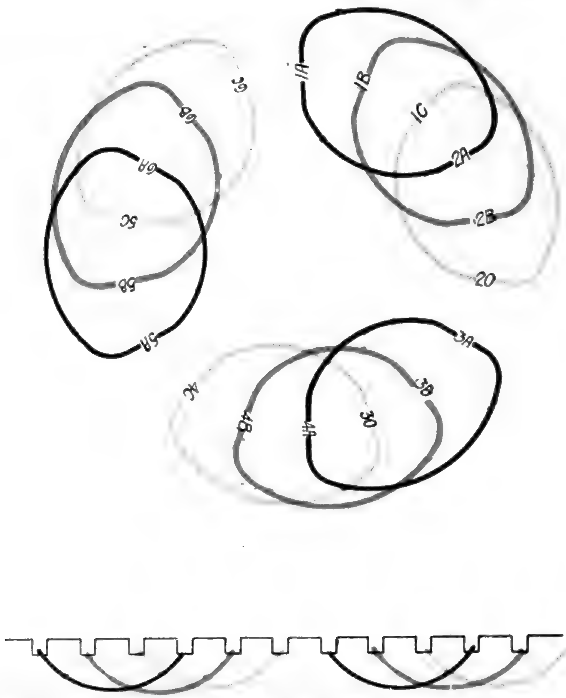


Fig. 229.—Three-phase Half-coiled Winding (one coil per phase per pair of poles).

Turning back for a moment to two-phase windings, it will be seen that the two-phase winding of Fig. 222 is similar to the three-phase winding of Fig. 229 in that the armature can be divided into sections without disturbing the coils.

As, however, there are only two coils in each group, there being only two phases, the ends can be laid up in two ranges. This is also the case with Fig. 227, but neither this winding nor Fig. 228 allows of the armature being divided into sections.

The above windings are the fundamental polyphase coil windings, and of them Fig. 227 is the most common for two-phase, and Fig. 223 the most common for three-phase. So far as divisibility of the armature and number of ranges in the winding is concerned, the following table is of interest as setting forth the properties of these fundamental windings:—

TABLE XII.

PROPERTIES OF POLYPHASE WINDINGS.

			No. of		Divisibility of

ERRATUM NOTE at p. 188.

In fig. 223, Plate XII., the coils of the red phase should be displaced through an angle of 60° or by one pole pitch, so that the outer periphery of the diagram will appear exactly as in fig. 220.

The winding of fig. 223 is intended to be identical with fig. 239, *g*, *h*, and *k* (also figs. 244, 247, and 250); while fig. 229 is identical with fig. 239, G, H, and K.

All references in the text to fig. 223 apply to fig. 223 as corrected in this manner.

While on this matter of ranges, we shall formulate a few general statements; but first a reference to Fig. 230 is desirable.

The sketches in Fig. 230 indicate a section through the armature core and the ends of the coils for various coil windings. *a* and *b* show single-range windings.

An inspection of any of the single-phase winding diagrams already given will show that all single-phase windings are laid up in one range. *c* and *d* show two-range windings. As has been seen, both two-phase and some three-phase windings can be laid up in this way. *e*, *f*, and *g* show three varieties of three-range windings with the coils laid back to a greater or less extent.

(1) For stationary alternator armatures, any of these varieties can be employed. It is generally preferable to keep the coils well back against the armature frame, and thus *b*, *d*, and *e* would be more common.

into sections just referred to, when we come to study the photographs of various types of winding with their diagrams, later on in this chapter.

In Fig. 223 the coils are no longer collected in groups of three, as in Fig. 229, and owing to this feature the armature cannot be divided into sections without dismembering several of the coils.

This winding is, however, capable of being laid up in two ranges in the manner shown in Figs. 230*c* and 230*d*.

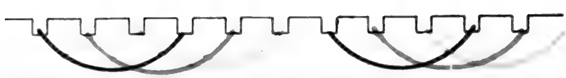


FIG. 229.—Three-phase Half-coiled Winding (one coil per phase per pair of poles).

Turning back for a moment to two-phase windings, it will be seen that the two-phase winding of Fig. 222 is similar to the three-phase winding of Fig. 229 in that the armature can be divided into sections without disturbing the coils.

As, however, there are only two coils in each group, there being only two phases, the ends can be laid up in two ranges. This is also the case with Fig. 227, but neither this winding nor Fig. 228 allows of the armature being divided into sections.

The above windings are the fundamental polyphase coil windings, and of them Fig. 227 is the most common for two-phase, and Fig. 223 the most common for three-phase. So far as divisibility of the armature and number of ranges in the winding is concerned, the following table is of interest as setting forth the properties of these fundamental windings:—

TABLE XII.

PROPERTIES OF POLYPHASE WINDINGS.

Fig. No.	No. of Phases.	Style of Winding.	No. of Coils per Phase per Pole Pair.	No. of Ranges.	Divisibility of Armature. A *can* be divided, B *can not.*
222	2	Half-coiled	1	2	A
227	2	Whole-coiled	2	2	B
223	3	Half-coiled	1	2	B
228	3	Whole-coiled	2	3	B
229	3	Half-coiled	1	3	A

This table brings out the point that the armature is not divisible unless the winding has one coil per phase per *pair* of poles, *i.e.* unless it is of the half-coiled variety. Also, both the two-phase windings can be laid up in two ranges; and, in fact, this is possible with *all* two-phase coil windings.

While on this matter of ranges, we shall formulate a few general statements; but first a reference to Fig. 230 is desirable.

The sketches in Fig. 230 indicate a section through the armature core and the ends of the coils for various coil windings. *a* and *b* show single-range windings.

An inspection of any of the single-phase winding diagrams already given will show that all single-phase windings are laid up in one range. *c* and *d* show two-range windings. As has been seen, both two-phase and some three-phase windings can be laid up in this way. *e*, *f*, and *g* show three varieties of three-range windings with the coils laid back to a greater or less extent.

(1) For stationary alternator armatures, any of these varieties can be employed. It is generally preferable to keep the coils well back against the armature frame, and thus *b*, *d*, and *e* would be more common.

Type *g* should only be used when the armature is built in two or more sections, as, if it is in one piece, the rotating field cannot be withdrawn owing to its fouling the lowest range of coils.

(2) For rotating armatures, any one except *g* is permissible; but here also it is desirable to keep the coils well back, and to

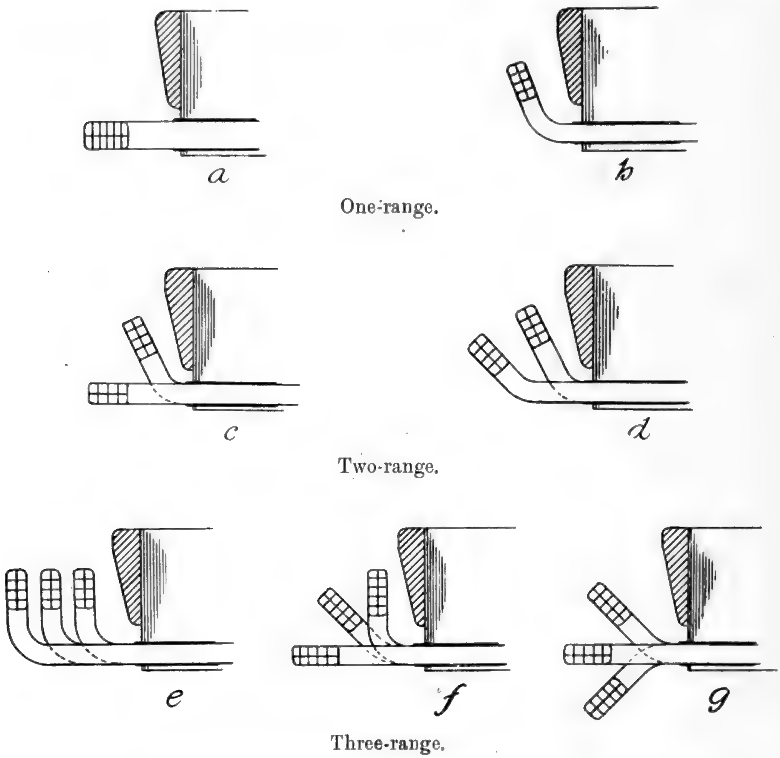


Fig. 230.—Section through Ends of Armature Coils.

strap them on to the core end plates for security. Thus *b*, *d*, *e*, and *f* will be preferable.

(3) For induction motors, the windings of the stator and rotor should come as near together as practicable to render the magnetic leakage a minimum. Thus *a*, *c*, and *f* will be preferable; and *g* may also be used for large motors, provided the rotor end windings (whether coils or squirrel cage) do not come in the way of the lowest range.

In either *a*, *c*, *f*, or *g* there is the danger, should anything on the rotor become loose and fly out, or anything get between the rotating and stator end windings, of the insulation on the lowest range becoming damaged, which may make it necessary to rewind that range.

We are now able to make the following general statements, the pertinence of which it will not be difficult to see from consideration of the above points.

Properties of Spiral Coil Windings.

1. All single-phase windings can be laid up in one range, irrespective of whether they are whole-coiled or half-coiled.

2. All two-phase windings can be laid up in two ranges, irrespective of whether there is *one* coil *per phase* per *pole* or per *pair of poles, i.e.* whether whole-coiled or half-coiled.

3. Three-phase windings can be laid up in either two or three ranges, according to the following conditions:—

(*a*) Three-phase two-range windings must have *one* coil per *pair of poles, i.e.* must be half-coiled.

(*b*) Three-phase whole-coiled windings (having *one* coil per phase per *pole*), *must* be three-range.

4. Any winding having a total number of coils which is *even*, can be laid up in two ranges irrespective of the number of phases.

5. Any winding having a total number of coils which is *odd*, may be laid up in two ranges if one of the coils is bent so that it is half in one range and half in the other (see fig. 231).

6. Divisibility of armature. If the armature is to be divisible into sections without disturbing the coils, the winding *must* have *one* coil per phase per *pair* of poles (*i.e.* must be half-coiled).

Of the above, No. 5, perhaps, needs further comment. Suppose we have a three-phase 12-pole half-coiled winding. There is one coil per phase per pair of poles.

$$\text{No. of pairs of poles} = \frac{12}{2} = 6.$$
$$\text{No. of coils per phase} = 6.$$
$$\text{No. of phases} = 3.$$
$$\text{Total number of coils} = 3 \times 6 = 18.$$

Now if we lay this winding up in two ranges, we shall have $\frac{18}{2} = 9$ coils in each range, which is quite practicable. If instead of twelve poles we have only six, then with one coil per phase per pair of poles we should have only three coils per phase, and for three phases, $3 \times 3 = 9$ coils in all. If we wish this to be a two-range winding, we should have $\frac{9}{2} = 4\frac{1}{2}$ coils in each range, or four coils in one range and four coils in the other, with the extra coil half in each range.

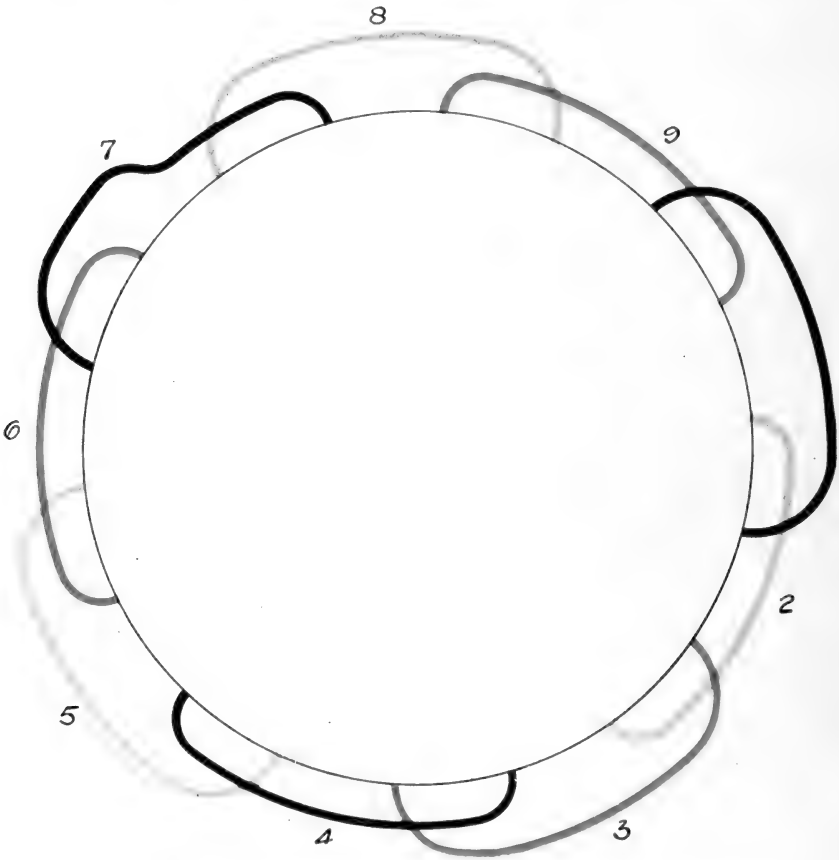


FIG. 231.—Three-phase Six-pole Half-coiled Winding (nine coils in two ranges).

This latter winding has already been shown in Fig. 223, where there are six poles, three phases, and nine coils.

Laid out as a two-range winding with a bent coil, the appearance of the ends of the armature coils is shown in Fig. 231, where we have coils 1, 3, 5, 8 in one range, coils 2, 4, 6, 9 in the other range, and coil 7, the bent one, half of which is really in each range.

A considerable advantage of the two-range over the three-range winding is that the former only requires two *kinds* of coil, whereas the latter requires three kinds. This is important if the coils are form-wound, as only two forms will be necessary for the two-range, against three for the three-range. It is, however, true that a two-range winding with a bent coil will require three forms, one for each range, and one for the bent coil, so that such a winding possesses no advantage over a three-range winding so far as the number of forms is concerned. If the windings are carried out by hand, the bent coil can be quite easily carried out by aid of a suitable winding-block (see p. 310, Chap. XII). The two-range

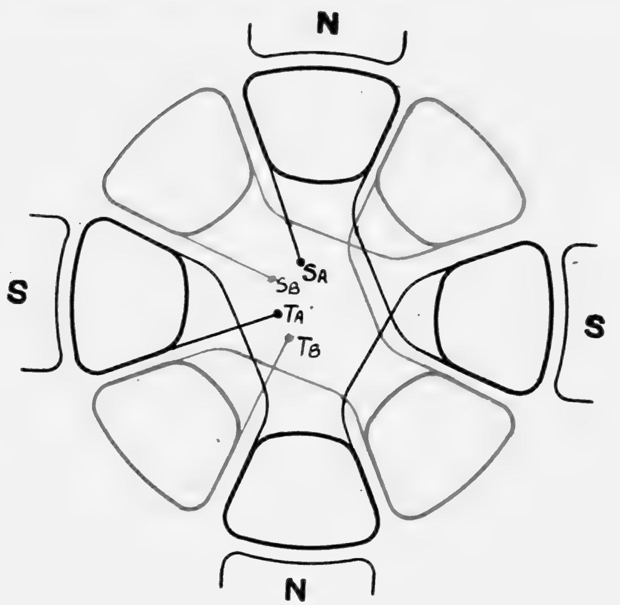


Fig. 232.—Four-pole, Two-phase, Short-coil Winding.

winding has also the advantage that the ends of the coils do not project out so far from the core as in a three-range.

Exception is taken to the above by two classes of winding which should be mentioned here. These may be designated respectively:—1. Short-coil windings; 2. Skew-coil windings.

Short-coil Windings.

Figs. 232 and 233 show diagrams for two-phase and three-phase short-coil windings. In these windings the coils of the various phases do not overlap, nor their end portions cross one another, but the coils are all of the same size and shape laid on the armature side by side. Thus in Fig. 232 we have two coils, one for each phase, within the pole pitch—not overlapping, as in Fig. 227, but placed side by side. Comparing with Fig. 227, the coils are much narrower, and hence their designation "short coils." Also, in Fig. 233, we have three coils within a double pole pitch. If for the moment we ignore the poles in Fig. 232, and imagine all the coils coloured black and connected in series, then we have a single-phase armature, and the number of poles will necessarily be twice what it was originally.

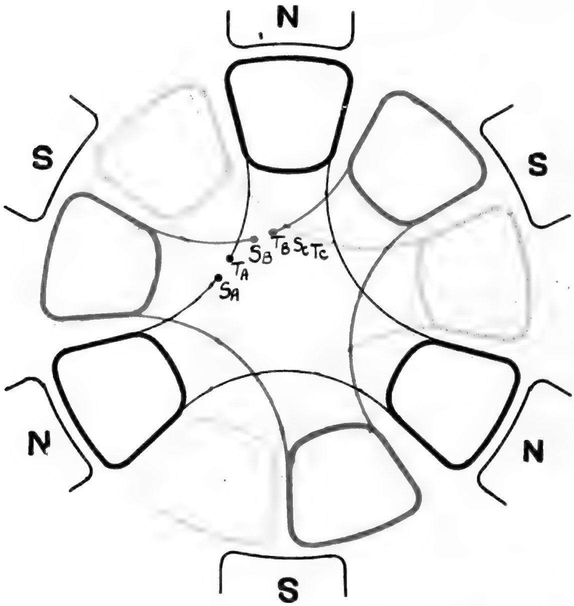


FIG. 233.—Six-pole, Three-phase, Short-coil Winding.

It follows that any single-phase coil-wound armature may be connected up as a two-phase short-coil winding if the total number of coils is a multiple of 2, and as a three-phase short-coil winding if the total number of coils is a multiple of 3. The number of poles as two-phase is one-half the number of poles as single-phase, and, as three-phase, one-third the number as single-phase. Conversely, any polyphase short-coil winding may be connected for single phase provided there is an even number of coils. The number of poles as single phase will be equal to the number of coils.

In the short-coil windings the mean length of the turn of a coil is reduced, and, consequently, the total length of conductor per phase. The disadvantage, and the reason why they are used very infrequently, is that the pole arc must be reduced until it is only about as wide as a coil, which entails a reduction in the pole area, and the periphery of the armature is not so well utilised.

Skew-coil Windings.

Fig. 234 will illustrate what is meant by a skew-coil winding. Here the coils are all of the same shape, and the winding is equivalent to an ordinary long-coil, or overlapping, winding.

The winding diagram for Fig. 234 will be the same as that shown above in Fig. 223. Whereas in the latter winding the overlapping

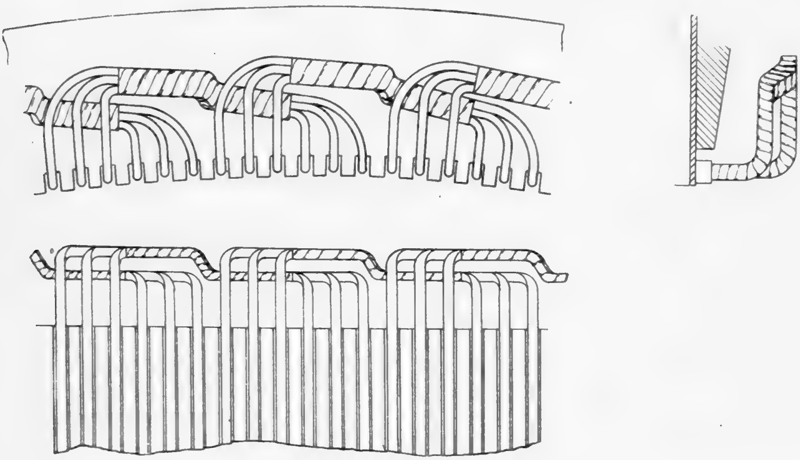


Fig. 234.—Skew-coil Winding.

of the ends of the coils is provided against by laying them up in ranges, in the skew-coil winding the ends of the coils are skewed so that they all lie up in order beside one another. The skew coil is probably not so easy to wind as an ordinary symmetrical coil, and the insertion of the last coil on the armature after winding is not an easy job. This type of winding is not used to to any great extent.

A point of considerable importance in all these winding schemes is the pressure between the adjacent coils. If one inspects Figs. 227 and 228 and considers phase A (black), it is evident that the maximum voltage exists between the points S_A and T_A, which is the machine terminal voltage. The pressure between the sides of the first and last coils is practically as great as the full terminal voltage. This pressure thus exists between groups of conductors lying very near together and in adjacent slots, and at this point the armature is most liable to insulation breakdown.

Turning now to the corresponding half-coiled windings of Figs. 219 and 220, the full pressure exists between the groups of conductors 1A and 6A; but in this case these groups are distant from each other by a space equal to the pole pitch, and, consequently, the risk of breakdown is not nearly so great.

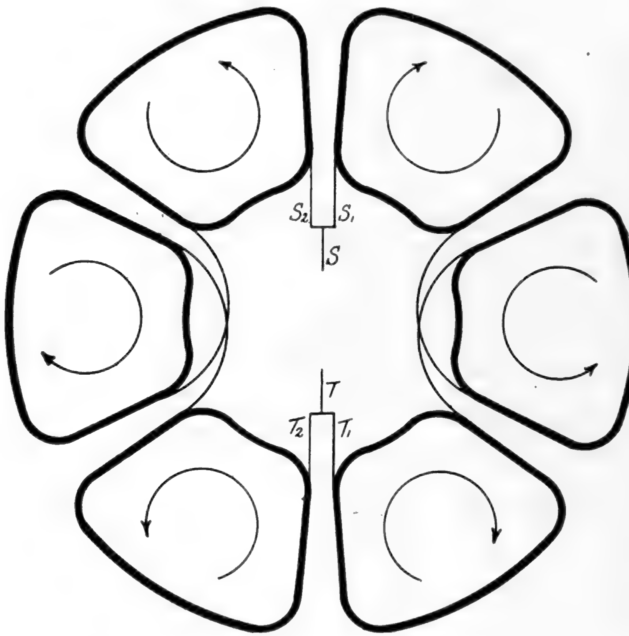


FIG. 235.—Parallel-connected Winding.

This is a point decidedly in favour of the half-coiled style of winding, and this point, together with the others enumerated, adds to its wide utility for three-phase windings.

The difficulty with the ordinary winding of the full pressure existing between adjacent coils can be obviated by connecting two halves of the winding in parallel, as indicated in Fig. 235. The right-hand half of this winding, consisting of three coils, has terminals S_1 and T_1; and the left-hand half, S_2 and T_2.

Connecting S_1 to S_2 and T_1 to T_2 puts the two halves in parallel, and the full pressure occurs between the points S and T, which are very remote from one another—being, in fact, diametrically opposite. Any of the phases, if the winding is polyphase, could be treated in a similar way.

In connection with this subject we give a number of photographs of various windings, most of which types have occurred in the foregoing study of polyphase windings. We have drawn out the winding diagram corresponding to each of these photos, and a study of the two together is very instructive.

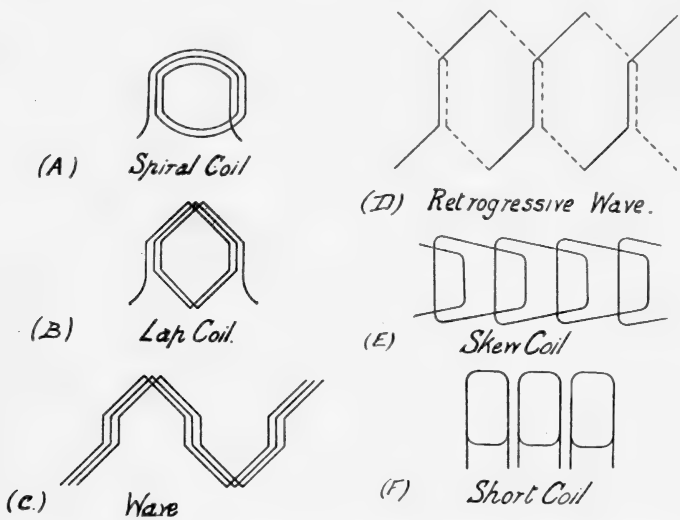


FIG. 236.—Alternating-current Winding Classification. Types of Coils.

In Figs. 236 to 239 our system of alternating-current winding classification and nomenclature, as employed in the preceding descriptions and explanations, is diagrammatically tabulated.[1] The terms employed may be re-stated as follows:—

By a "coil" we designate the group of turns subtending one pole belonging to one phase irrespective of the number of turns in the coil.

Fig. 236, A, B, E, and F, show diagrammatic representations of the four types of coil to which reference has already been made. These are respectively—

(A) Spiral coil. (B) Lap coil.
(E) Skew coil. (F) Short coil

[1] A chart showing the derivation of all these types of windings is given in Plate XIV.

The other two types, C and D, shown in Fig. 236, are respectively elements of a wave winding C and a retrogressive wave winding D. The development of these two types of winding from the elementary fundamental windings is considered in further detail on pp. 229 and 232. The "coil" may have its conductors concentrated in a single slot on each side, or it may have them distributed at each side in two, three, four or more slots.

If the conductors on one side of the coil lie in only one slot we designate the coil a "single coil." If they are spread over two slots the coil is a "double coil"; if over three slots, a "triple coil," and so on.

In the top row of windings, *i.e.* those marked *a* and *g* in Figs. 237, 238, and 239, the coils are "single coil," as marked at the left-hand side of the row.

In the second row, *i.e.* those marked *b*, *e*, *h*, and *m*, in Figs. 237, 238, and 239, the coils are "double coil"; that is, each coil consists of two parts in separate slots.

In the third row, *i.e.* *c*, *f*, *k*, and *n*, they are "triple coil"; that is, in three parts, the conductors on each side of the coil being distributed in three slots.

In Fig. 237, which relates only to single-phase windings, we have shown the outline of the slots, but in Figs. 238 and 239, where there are twice and three times the number of slots in the corresponding diagrams of Fig. 237 (as Figs. 238 and 239 are for two and three phases respectively), the coils have been distinguished by different varieties of lines; thus, full dotted and chain lines for the different phases.

Having now explained the terms "single-coil," "double-coil," and so on, we will explain the other sub-divisions in Figs. 237, 238, and 239.

Fig. 237 is headed "single-phase," and is devoted exclusively to single-phase windings. Under this heading there are two sub-headings, viz. "whole-coiled" and "half-coiled" (as there are also in Figs. 238 and 239).

The distinction which has already been explained between these two headings will be seen by an inspection of any of the windings coming under them.

By "whole-coiled" we denote that the whole system of poles is subtended by coils, *i.e.* each pole has a coil opposite it on the armature, which is the case in all the windings in Fig. 237, *a*, *b*, *c*, *e*, and *f*.

In the "half-coiled" windings, however, only one half of the total number of poles are subtended by coils, *i.e.* every other pole has a coil opposite it on the armature, every alternate pole having no coil opposite to it.

This is so in all the windings in Fig. 237, *g*, *h*, *k*, *m*, and *n*, where it will be seen that the portion of the armature opposite alternate poles is not occupied by coils.

Similarly, in the two phase windings of Fig. 238, the whole-coiled windings of Figs. *a*, *b*, *c*, *e*, and *f* have two coils for each pole, *i.e. one coil per phase per pole,* and the half-coiled windings Figs. *e*, *g*, *h*, *k*, *m*, and *n* have two coils subtending every alternate pole, *i.e. one coil per phase per pair of poles.*

Also in the three phase windings of Fig. 239, the whole-coiled windings, Figs. *a*, *b*, *c*, *e*, and *f*, have three coils for each pole, *i.e. one coil per phase per pole,* and the half-coiled windings, Figs. *g*, *h*, *k*, *m*, and *n*, have three coils subtending every alternate pole, *i.e. one coil per phase per pair of poles.*

Thus, as explained, the distinction between the "whole-coiled" and "half-coiled" varieties is that the "whole-coiled" has *one coil per phase per pole,* while the "half-coiled" has *one coil per phase per pair of poles.*

It may be noted that for a given number of poles and phases the half-coiled winding has one-half the total number of coils that the whole-coiled winding would have.

By way of illustrating the nomenclature, the winding in Fig. 238, *h*, would be designated a "two-phase, half-coiled, double-coil, spiral winding"; or that in Fig. 239, *f*, a "three-phase, whole-coiled, triple-coil, lap winding."

We have already on pp. 191 and 192 summarised the properties of spiral coil windings with regard to the number of ranges in which the winding may be laid up. We are now in a position to make out from Fig. 239 a table showing the number of ranges possible with each of the windings (lap coil windings are exempted, as, by reason of the two arms of the V end connectors being formed in two separate planes, they lie up together in order).

Table XIII. shows the number of ranges for all the spiral coil windings in Fig. 239, from which the following conclusions may be drawn :—

(*a*) All the whole-coiled three-phase windings, Figs. *a*, *b*, and *c*, must be three-range.

(*b*) The half-coiled windings may be three-range, Figs. G, H, and K, or two-range, Figs. *g*, *h*, and *k*, the possibility of three or two-

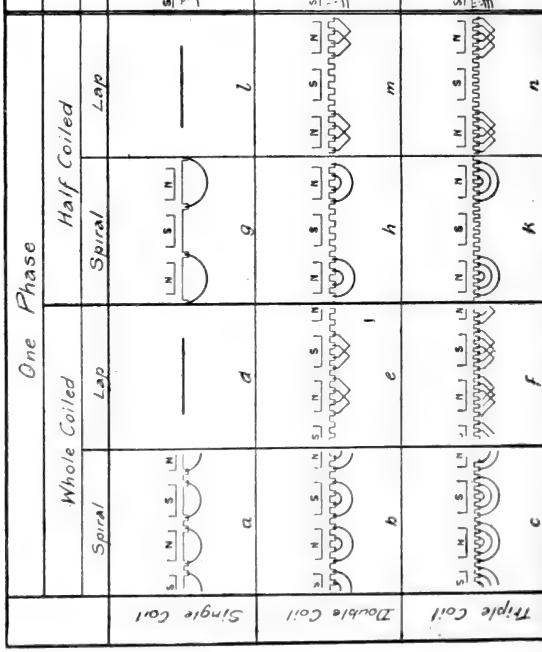


FIG. 237.

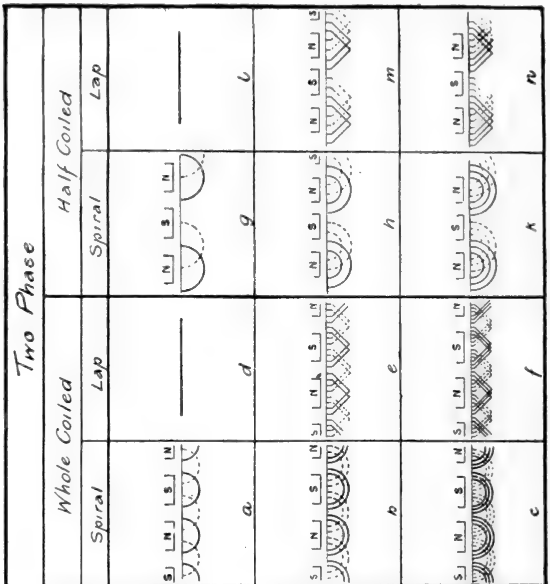


FIG. 238.

Scheme for Alternating-current Winding Nomenclature.

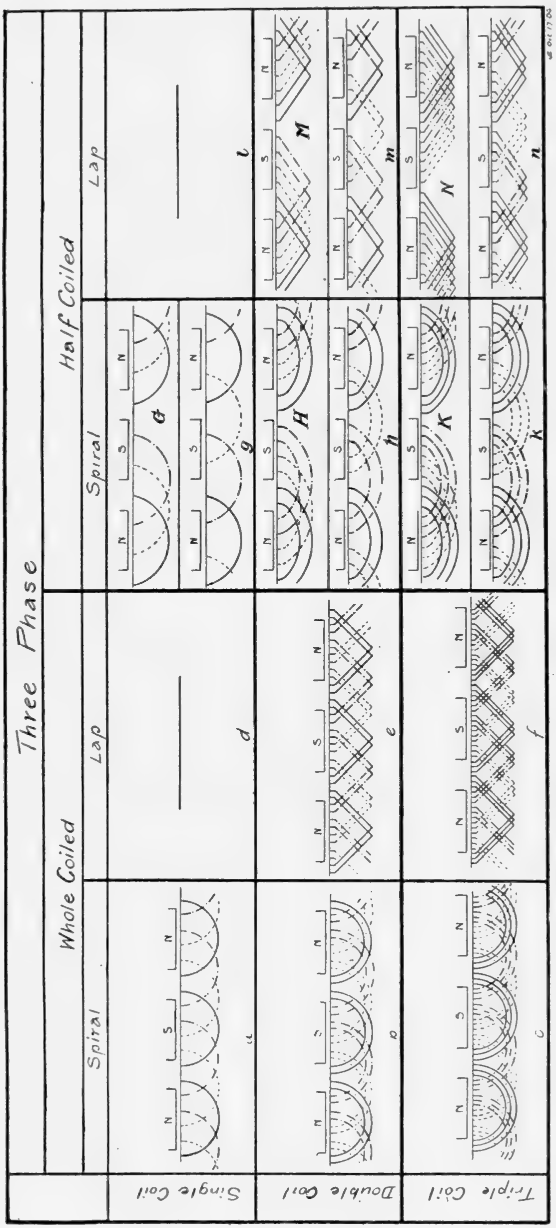


FIG. 239.—Scheme for Alternating-current Winding Nomenclature.

ranges depending on the grouping of the coils, which will be seen on comparing Figs. *g*, *h*, and *k* with G, H, and K respectively.

TABLE XIII.

NUMBER OF RANGES FOR THREE-PHASE SPIRAL COIL WINDINGS IN FIG. 239.

	Three-phase Spiral Coil Windings.	
	Whole-coiled.	Half-coiled.
Single coil . .	*a*, 3-range	G, 3-range *g*, 2-range
Double coil .	*b*, 3-range	H, 3-range *h*, 2-range
Triple coil . .	*c*, 3-range	K, 3-range *k*, 2-range

The windings in Figs. G, H, and K are, strictly speaking, grouped as six-phase windings (and in connecting them up Y or Δ one phase must be reversed, as noted on p. 183), while Figs. *g*, *h*, and *k* are true three-phase windings.

Figs. 237, 238, and 239 show that the number of slots per pole per phase is determined simply by (1) whether the winding is single, double, or triple coil, and (2) whether it is whole-coiled or half-coiled.

Examination of the numbers of slots in the various windings enables us to draw up Table XIV., which shows the number of slots per pole per phase for single and polyphase windings. For instance, a triple-coil whole-coiled winding (Figs. *c* and *f* in Figs. 237, 238, and 239) has six slots per pole per phase, but a triple coil half-coiled winding (Figs. *k* and *n*) has only three slots per pole per phase.

In single-phase windings the total number of slots per pole is simply the number of slots per pole per phase, and thus in Table XV. the number of slots per pole for single-phase windings is copied from Table XIV. With two-phase windings the total number of slots per pole is twice the number of slots per pole per phase, and with three-phase windings three times. Thus we are able to fill up the number of slots per pole in Table XV. for two and three phase by multiplying the corresponding single phase values by 2 and 3 respectively.

TABLE XIV.

SLOTS PER POLE PER PHASE FOR THE WINDINGS IN FIGS. 237, 238, AND 239.

	Slots per Pole per Phase.	
	Whole-coiled.	Half-coiled.
Single coil . . .	2	1
Double coil . .	4	2
Triple coil . . .	6	3
Quadruple coil . .	8	4

TABLE XV.

SLOTS PER POLE FOR THE WINDINGS IN FIGS. 237, 238, AND 239.

	Slots per Pole.					
	One-phase.		Two-phase.		Three-phase.	
	Whole-coiled.	Half-coiled.	Whole-coiled.	Half-coiled.	Whole-coiled.	Half coiled.
Single coil .	2	1	4	2	6	3
Double coil .	4	2	8	4	12	6
Triple coil .	6	3	12	6	18	9
Quadruple coil .	8	4	16	8	24	12

As an example of the use of these tables let us consider a three-phase, half-coiled, triple coil spiral winding in two ranges.

Fig. 239 shows us that the half-coiled triple coil winding may be either of Figs. 239 *k* or 239 K. Table XIII. shows that of these two, *k* is two-range, whereas K is three-range. Hence Fig. 239 *k* is the winding described by the above title. From Table XIV. we ascertain that this winding has three slots per pole per phase, *i.e.* it is a three-slot winding. By multiplying by the number of phases 3, or by reference to Table XV., we have the number of slots per pole = 9.

In describing a winding by means of this nomenclature it may be useful to prefix or suffix the title by the number of slots per pole per phase; thus one-slot (or uni-slot), two-slot, five-slot, etc., but this term should not be confused with the terms single coil, double coil, etc.

It will be seen that there are three factors employed in determining a winding, viz: (1) Whether it is whole-coiled or half-coiled; (2) the multiplicity of the coil—whether single or multi-coil; (3) the number of slots per pole per phase—whether uni-slot or poly-slot.

It will also be appreciated from the relations set forth in Table XIV. that any two of the factors determine the other remaining one. Consequently it would be quite sufficient in describing a winding to state only two, which is the case in Figs. 237, 238, and 239. In these figures the two factors set forth are Nos. 1 and 2, but these figures could have been just as well prepared from the basis of factors 1 and 3, *i.e.* whether whole-coiled or half-coiled, and the number of slots per pole per phase.

As the system in this chapter has been evolved from the two factors 1 and 2 we shall adhere to this designation in studying the windings which now follow, but we shall also add to the title of each winding the factor 3, the number of slots per pole per phase, uni-slot, two-slot, etc.

It may be noted that the latter figure is the one which the designer employs for the winding in any particular case, and it is also more convenient in the case of wave windings (see p. 229).

APPLICATION OF NOMENCLATURE SCHEME.

Two-range Windings.

We now give a number of photographs of various different windings which we shall study by means of their diagrams, and the application of the above system of nomenclature to them.

Fig. 240 shows a photograph of a stationary armature having seventy-two slots wound with twelve coils. This winding is a two-range winding, there being thus six coils in each range. Fig. 240 shows clearly one range laid back against the frame, and the other standing in front of it. Each coil is distributed over three slots at each side. If there were only one conductor in each slot, then the winding diagram of Fig. 241 would be a true representation of the actual winding.

The winding would actually consist of several conductors per slot, as will be seen from the thin connectors between the coils; but if each radial line in Fig. 241 is regarded as a group of conductors, the same in number as there are conductors per slot, the diagram of Fig. 241 will represent the winding.

An individual coil would appear as shown in Fig. 242; but it is too tedious to draw out all the coils in this manner, so long as the number of conductors per slot is stated and borne in mind.

In Fig. 241 we have drawn six coils with full lines and six with dotted lines. The six full-line coils represent the front range, and the dotted coils the back range. This plan is useful to distinguish between the ranges in the case of two-range windings, and does not confuse with the distinction between the phases where different colours are used for each phase.

In Fig. 241 we have not connected up the coils to one another, as this particular winding possesses the property that it may be connected as either a two-phase or a three-phase winding. We shall demonstrate this by connecting it up in both ways.

Two-phase.—For a two-phase winding, as there are twelve coils, there must be six coils per phase; and one phase will take in the six coils in one range, and the second phase the six coils in the other range. Thus phase A must consist of the coils numbered I, III, V, VII, IX, and XI; phase B of coils II, IV, VI, VIII, X, and XII. Now, since the neighbouring coils of one phase lie close together—for instance, see the group of conductors 10, 11, and 12, and the group 13, 14, and 15—with no space between them, we must arrange for *one coil* per phase *per pole.* Thus we shall have six poles, one subtending each coil of one phase; and in connecting up the coils we must arrange for the direction of current circulation in adjacent coils to be opposite (see Figs. 203 and 204).

Hence we connect the end of coil I to the end of coil III, the beginning of III to the beginning of V, and so on, reversing each coil on its predecessor and making it of opposite polarity.

Had we connected up the coils all in the same sense, we should have required twelve poles; but this would be impracticable, as there is no room between the adjacent coils (as, for instance, between coils I and III) for the other six consequent poles.

Connecting up the other phase in a similar way gives us a six-pole two-phase winding, with terminals S_A T_A, S_B T_B, as in fig. 243.

The number of slots per pole is $\frac{72}{6} = 12$, or six per pole per phase. As this winding has *one* coil per phase per *pole*, a single coil should cover six slots on *both* sides, *i.e.* three on each side (see p. 174); this, it will be seen, is the case in the winding diagram.

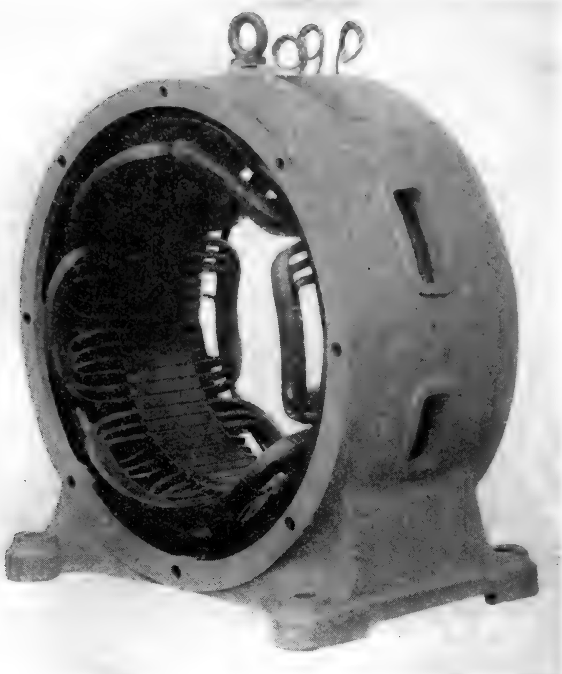


FIG. 240.—Wound Stator with Spiral Coils. Twelve Coils in two Ranges.

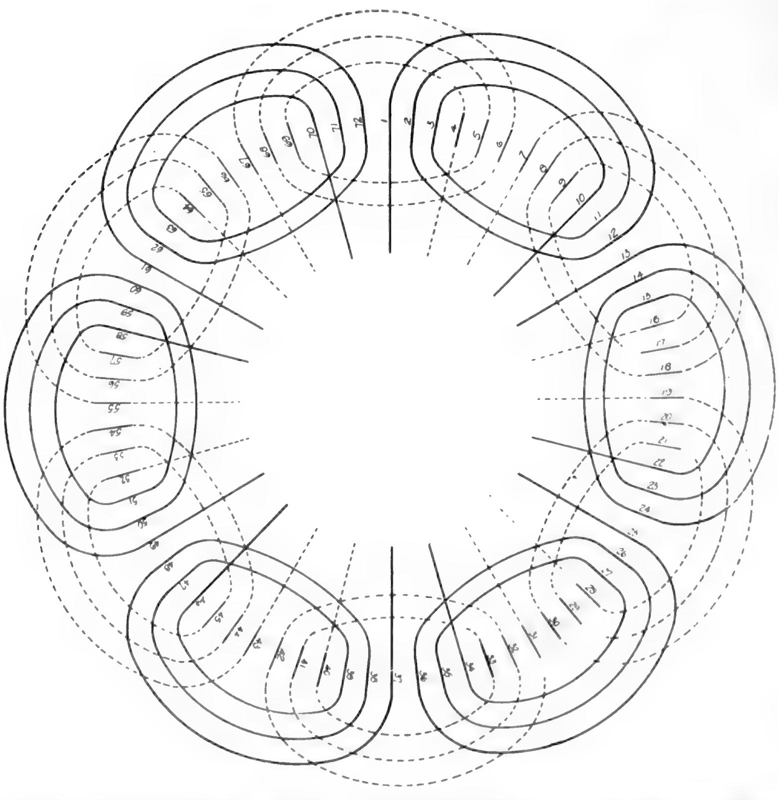


FIG. 241.—Triple-coil Spiral Winding. Twelve Coils in two Ranges. Seventy-two Slots.

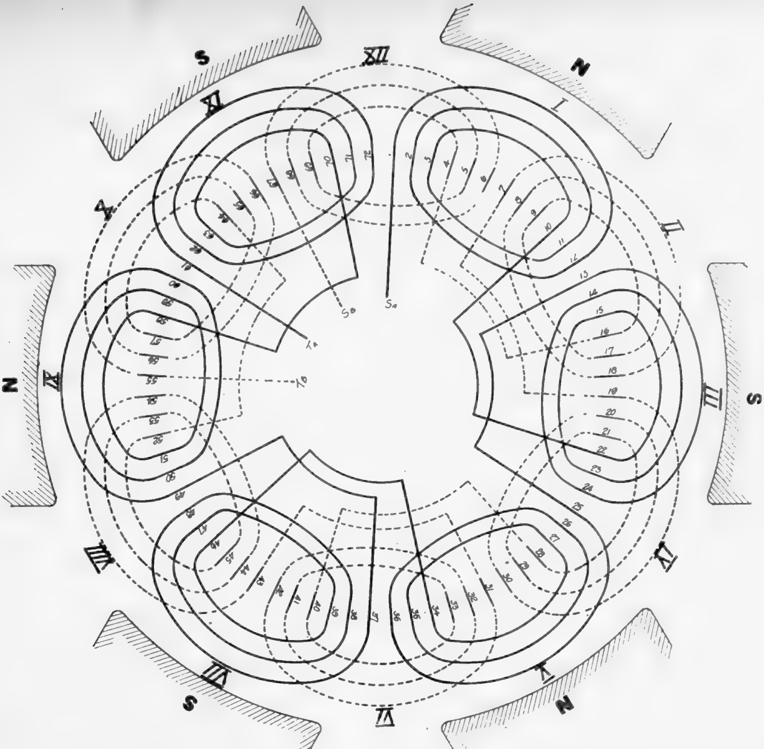


FIG. 243.—Six-pole, Two-phase, Whole-coiled, Triple-coil, Six-slot Spiral Winding.

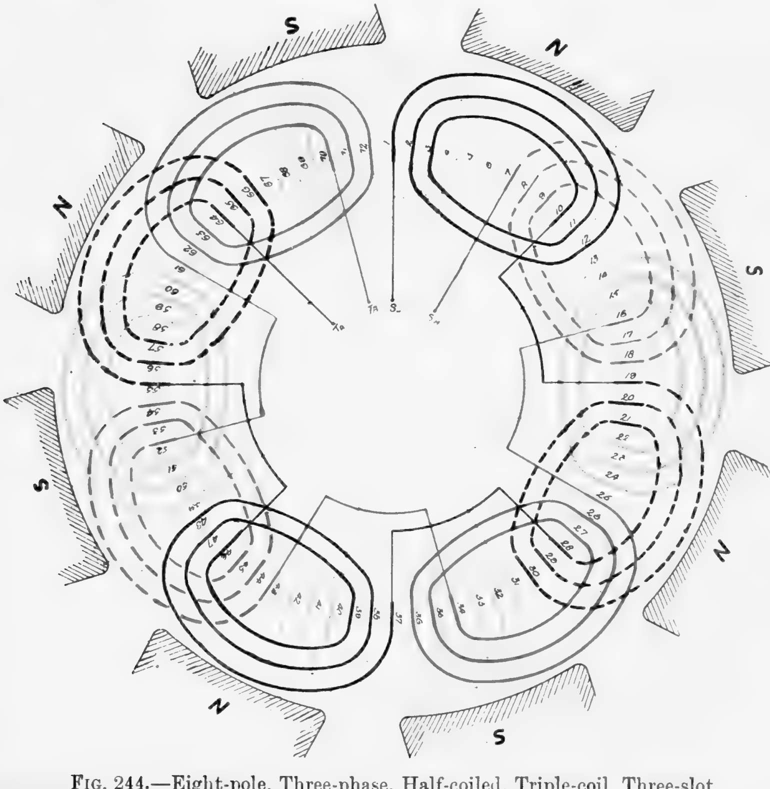


FIG. 244.—Eight-pole, Three-phase, Half-coiled, Triple-coil, Three-slot Spiral Winding. In two Ranges.

Slots 1 to 12 lie within a pole pitch; and coil I covers slots 1, 2, and 3 on one side, and slots 10, 11, and 12 on the other—six slots in all.

The spread of the winding is $\frac{12}{6} = 50\ \%$.

The designation of this winding is a six-pole, two-phase, whole-coiled, triple-coil, six-slot spiral winding.

Three-phase.—For a three-phase winding there will be $\frac{12}{3} = 4$ coils per phase. Phase A will consist of coils I, IV, VII, and X; phase B of coils II, V, VIII, and XI; phase C of coils III, VI, IX, and XII.

Now consider, for purposes of connecting up, phase A alone. Neighbouring coils, as coils I and IV, do not lie close together (as was the case in the two-phase winding), but they are distant,

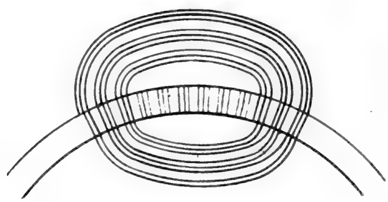


Fig. 242.—Nine-turn Triple Coil.

as between conductors 12 and 19, an amount about equal to the width of one coil. If we place one pole opposite coil I and another opposite coil IV, the space between these coils can be occupied by another pole; and carrying this out around the armature, we obtain eight poles in all. Thus there are eight poles and four coils per phase, which gives *one* coil per phase *per pole pair*; and herein this winding differs from the same connected as a two-phase, where there are six poles and *one* coil per phase *per pole.*

A reference back to Fig. 201 will be useful at this point. Here we started out with six poles, and evolved a half-coiled winding which had three coils per phase or *one* coil per phase *per pole pair.* In this diagram it will be seen that the neighbouring coils of one phase are displaced from one another by an amount equal to the pole-pitch, the same as occurs in Fig. 244. In Fig. 244 we have coloured the three phases A, B, and C, black, red, and blue (still retaining the dotted coils to distinguish the front and back ranges irrespective of their colour), and have also added the eight poles. Since the four coils of one phase are situated under poles all of which are of the same polarity (as coils I, IV, VII, and X), the direction of current circulation will be the same in all of them. Hence we must connect up the four coils in the same direction:—

The end of coil	I	to the beginning of coil		IV
„	IV	„	„	VII
„	VII	„	„	X,

leaving the beginning of I and the end of X for terminals S_A and T_A. Similarly, connecting up the other two phases, B and C, gives the completed diagram of Fig. 244. This winding is now an 8-pole, three-phase, half-coiled, triple-coil, three-slot spiral winding in two ranges. The number of slots per pole is $\frac{72}{8}=9$, or 3 per pole per phase, which will also be seen from Tables XIV. and XV. This winding having *one* coil per phase per *pole pair*, a single coil should cover three slots on *one* side (see p. 174).

This will be seen from the diagram in Fig. 244. Slots 1 to 9 lie within a pole pitch, and of these slots 1, 2, and 3 are covered by one side of coil No. I of phase A.

The spread of the winding is thus $9/3=33$ per cent.

One interesting point is brought out by retaining the dotted-line coils to represent the back range in Fig. 244. It will be seen that each phase consists of two full-line coils and two dotted-line coils—two in the front range and two in the back. The three phases are exactly similar, and should the length of the mean turn of the front range coil differ from that of the back range coil, the phases will still all have the same total length of conductor in them, and be consequently of the same resistance and quite balanced.

The following are a few points which may be noted in connection with this winding:—

1. Any three-phase two-range winding having an even number of coils per phase will have half of that number situated in one range and half in the other range, and the three phases will be exactly similar.

The following table shows a comparison between the two-phase and three-phase arrangements of the two-range twelve-coil winding shown in Figs. 243 and 244.

Table XVI.

PROPERTIES OF WINDING IN FIG. 241 CONNECTED AS TWO- AND THREE-PHASE.

Fig. Number	243	244
No. of ranges	2	2
„ coils	12	12
„ coils per range	6	6
No. of phases	2	3
„ coils per phase	6	4
„ poles	6	8
„ poles per coil per phase	1	2
„ slots per pole per phase	6	3
Spread of coil—No. of slots	6	3
No. of slots per pole	12	9
Spread of coil—per cent.	50%	33 %
Style of winding	whole-coiled	half-coiled

This matter of the applicability of a single winding to both two-phase and three-phase is of considerable interest, as it determines the number of slots permissible for armatures to be used for both two- and three-phase with two-range windings.

2. The condition for any two-range winding to be either two or three-phase is simply that the total number of coils must be a multiple of 6 (2×3).

From this follow directly the numbers of slots which may be used with such armatures. A single coil cannot occupy less than two slots, one on each side; and as the minimum number of coils must be six, the minimum number of slots is $6 \times 2 = 12$.

3. Any permissible number of slots must be a multiple of 12—thus 12, 24, 36, 48, 60, and 72, etc., are the possible numbers of slots to be used for armatures capable of being wound with both two and three-phase two-range windings.

In such a winding the number of poles *equals* the number of coils per phase when connected for two-phase, and *twice* the number of coils per phase when connected for three-phase; the latter winding is half-coiled and the former is not. (See also p. 191 as to the conditions under which a three-phase winding can be laid up in two ranges.)

Fig. 245 illustrates a wound stator for an induction motor, the winding of which has twelve coils laid up in two ranges, exactly similar to Fig. 240. As is the case with the winding of Fig. 240, the winding of Fig. 245 can be arranged as a two-phase six-pole winding or a three-phase eight-pole winding; the properties of each of these windings being exactly the same as is set forth in Table XVI.

It will be seen from Fig. 245 that one coil is spread over five slots on one side, *i.e.* it is a quintuple coil, whereas in Fig. 240 this spread was three slots, *i.e.* a triple coil. Also, there are three conductors in each slot, and thus the number of turns in each coil is $5 \times 3 = 15$. As has been stated above, it is too tedious to draw out a winding diagram showing each individual conductor, and such a diagram would be unnecessarily complicated. It is sufficient to adhere to the rule of regarding each single radial line in the winding diagram as representing the contents of a single slot —in this case, three conductors.

The winding diagram would be exactly the same as Figs. 243 or 244, according as it is two-phase or three-phase, except that the coils shown in these figures should be replaced by coils similar to that of Fig. 246. The actual coil of fifteen turns would be as shown in Fig. 246.

For ordinary purposes in the winding shop it is not necessary to provide the winder with a complete diagram of the whole winding; but so long as he has a diagram of the coil element and also a diagram showing the connections between the coils, these are sufficient to carry out the winding form. Thus Fig. 246 defines the coil element, and, working to this, the first coil would be wound from slots 1 to 20, 2 to 19, 3 to 18, 4 to 17, 5 to 16, covering five slots on each side. Slots 6 to 10 and 11 to 15 are left for the front range of coils. So long as the first coil is wound correctly, with the required number of conductors in each slot, the remaining coils cannot help but come in their correct positions when they are wound progressively round the armature.

For connecting up the coils, a diagram in which each of them is shown as a single thick line is sufficient, and this also serves to make certain the location of each coil. Such a diagram as that given in fig. 247 would be sufficient, and in this diagram each radial line would actually represent fifteen conductors distributed over five slots, that is, one side of a quintuple coil.

We have adhered to our convention of representing the back range by dotted lines and the front range by full lines, and we have connected up the winding as a three-phase eight-pole winding with terminals S_A $T_{A'}$, S_B $T_{B'}$, S_C $T_{C'}$. The winding is also connected up star fashion; thus $T_{A'}$, $T_{B'}$, T_C are connected together (see p. 180), leaving $S_{A'}$, $S_{B'}$, S_C for the line.

The title for this winding is an eight-pole, three-phase, half-coiled, quintuple coil, five-slot spiral winding in two-ranges and Y connected.

Before leaving two-range coil windings, reference will now be

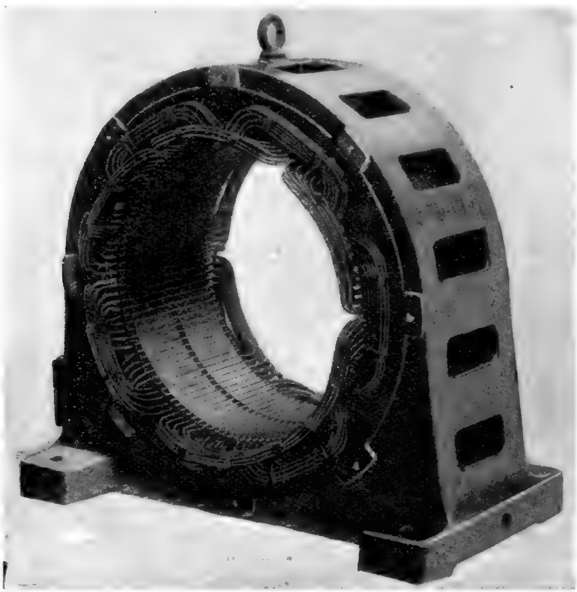


FIG. 245.—Eight-pole, Three-phase, Half-coiled, Quintuple Coil, Five-slot Spiral Winding in two ranges.

made to another type of diagram which will be introduced in conjunction with the photographs of portions of windings shown in Figs. 248 and 249.

These windings are precisely similar except for the number of conductors per slot. They are both two-range windings, and in each case the coil covers two slots on one side.

The title for these windings is a three-phase, half-coiled, double-coil, two-slot spiral winding in two-ranges. The winding diagram is shown in Fig. 250 for three-phase. This diagram differs from all those already given, in several respects.

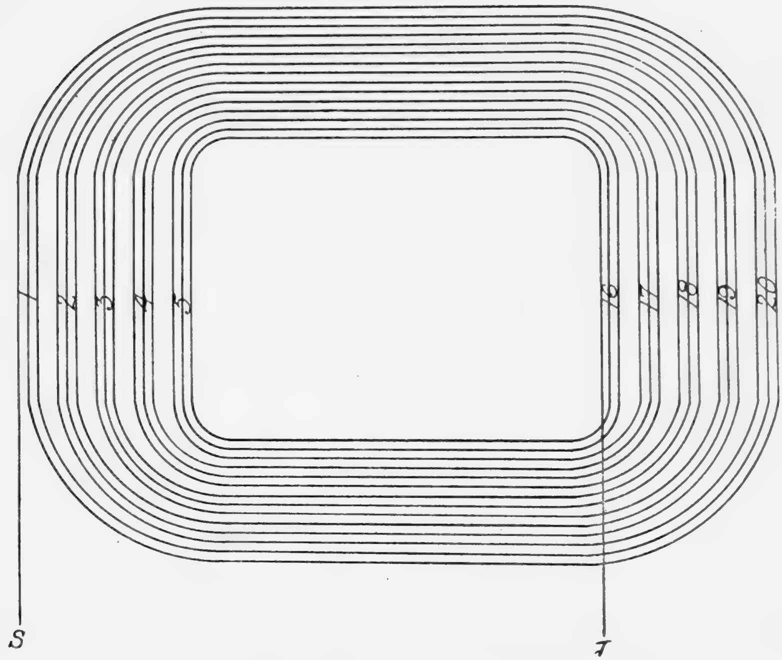


FIG. 246.—Fifteen-turn Quintuple Coil.

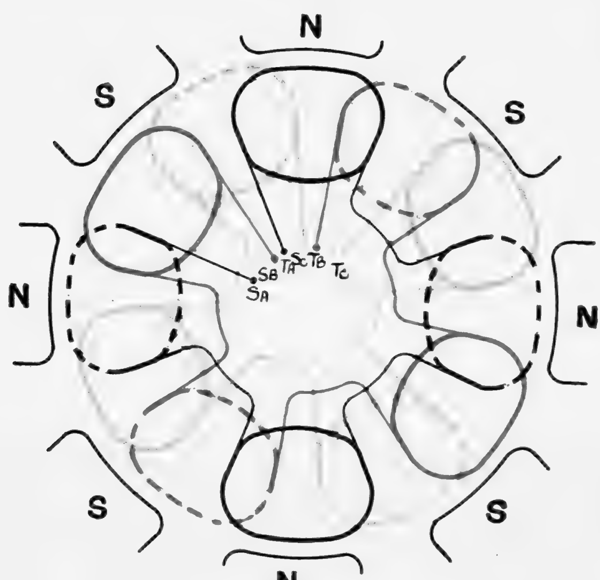


FIG. 247.—Diagram of Connections for Eight-pole, Three-phase, Half-coiled Winding.

The two ranges are distinguished by drawing their respective coils broad and narrow, as shown. The winding is repre-

FIG. 248.—Dick, Kerr & Co. Alternator. Three-phase, Half-coiled, Double-coil, Two-slot Spiral Winding in two ranges.

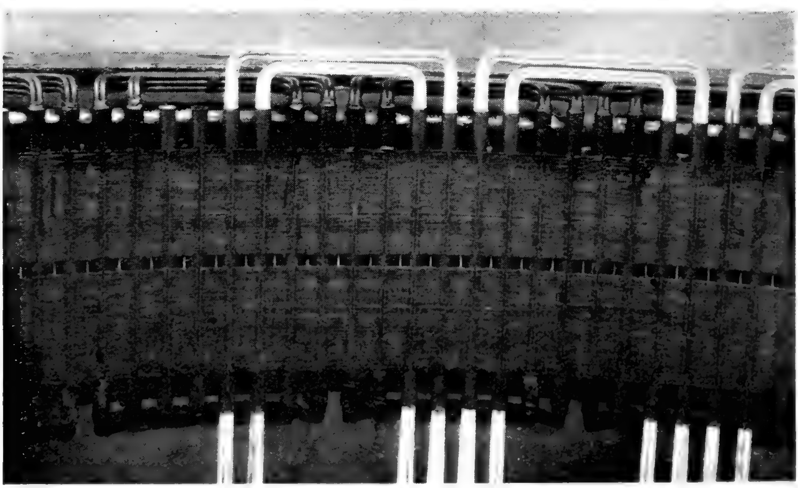


FIG. 249.—Allmanna Svenska Elektriska Aktiebolaget. Three-phase, Half-coiled, Double-coil, Two-slot Spiral Winding in two ranges.

sented in a developed form which is equivalent to rolling the surface of the armature out on the paper. This type of diagram is more useful for very large armatures which have a great

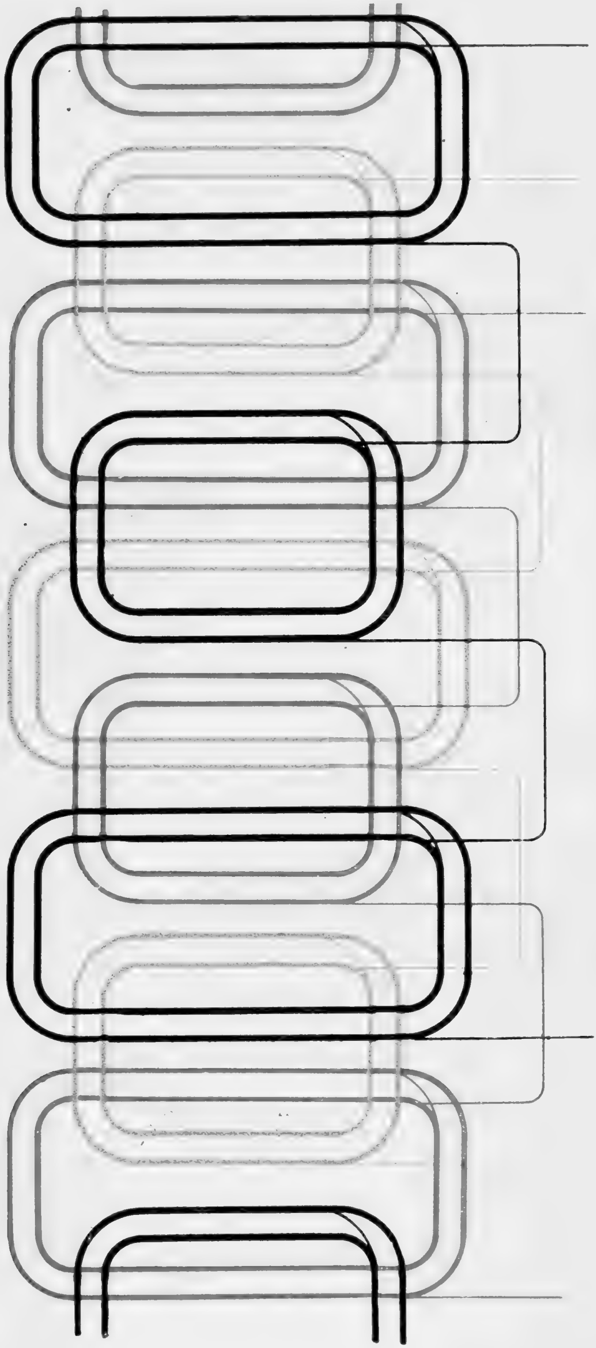


Fig. 250.—Three-phase, Half-coiled, Double-coil, Two-slot Spiral Winding in two ranges.

number of coils, as in Figs. 248 and 249. In connecting up a winding from the diagram in Fig. 250, the coils would be progressively connected up around the armature in the way shown in the diagram, and the terminals obtained after having connected up all round.

Fig. 248 shows the lower half of a large armature which is divided horizontally. It will be seen that the coils near the joints in the armature are removed, as the winding does not permit of the armature being divided without disturbing these coils, as will be seen from the table on p. 189.

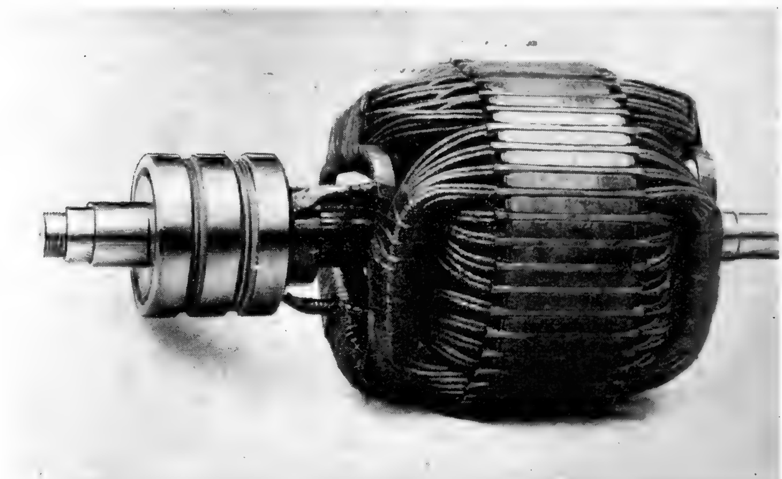


FIG. 251.—Wound Rotor. Four-pole, Three-phase, Half-coiled, Quadruple-coil, Four-slot Spiral Winding in two ranges, Y-connected.

As this armature has open slots the coils may be form wound, and those occurring at the division can be slipped into place after the two halves of the machine are assembled on site. If the slots are so nearly closed that form-wound coils cannot be employed, it is necessary for the coils at the joints of the armature to be wound on site by hand, which is undesirable.

Fig. 251 illustrates a three-phase four-pole wound rotor for an induction motor. The winding has six coils laid up in two ranges. There are 48 slots, and thus 16 slots per phase. The number of slots per pole per phase is $\frac{16}{4}=4$. This number will be seen to be the spread of a coil on one side, which is correct, as this winding has *one* coil per phase per *pole pair*.

The diagram for this winding is given in Fig. 252, where it is shown star connected. The designation is four-pole, three-phase, half-coiled, quadruple-coil, four-slot spiral winding, in two ranges, Y-connected.

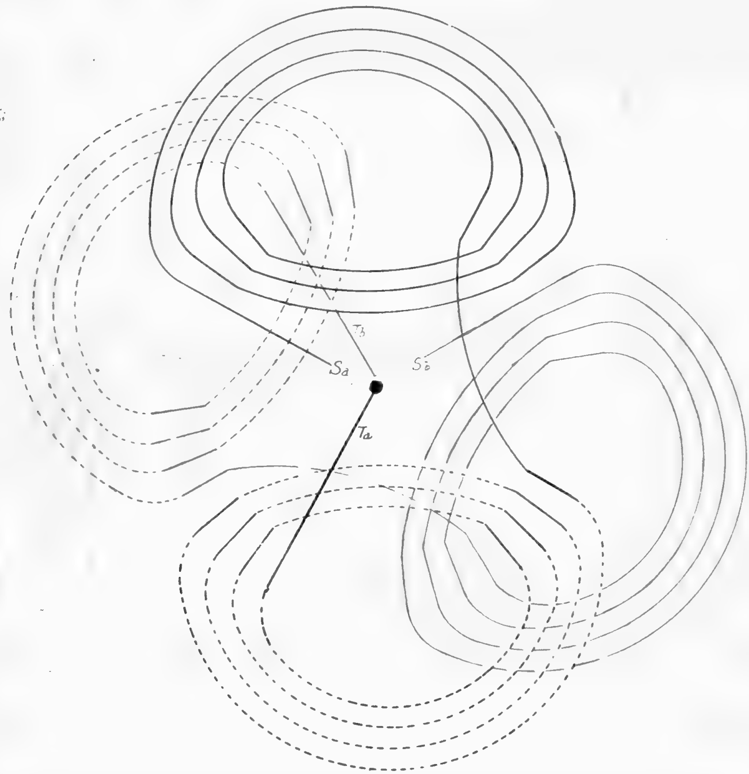


FIG. 252.—Four-pole, Three-phase, Half-coiled, Quadruple-coil, Four-slot Spiral Winding in two ranges, Y-connected.

THREE-RANGE WINDINGS.

We now proceed to give photographs of a few typical three-range windings and the corresponding winding diagrams.

As these relate to large armatures with many coils, we shall employ the developed type of winding diagram in connection with them similar to that in Fig. 250.

In the case of two-range windings we were able to distinguish between the ranges by full and dotted lines, and for three ranges we should need three varieties of lines, which becomes complicated. It is better to distinguish the ranges on the developed diagram by drawing one range with broad coils, the second with coils of medium breadth, and the third with narrow coils. A diagram on these lines is shown in Fig. 254, which is the diagram for the winding of which a photograph is given in Fig. 253.

This winding is of the type *g* shown in Fig. 230, having one range bent back away from the air-gap, the second range pro-

Fig. 253.—Three-phase, Half-coiled, Double-coil, Two-slot Spiral Winding in three ranges (six-phase grouping).

jecting out straight, and the third range bent forward over the air gap.

The bad feature of this winding where one range is bent over the air-gap, is that the rotor cannot be withdrawn without taking off the top half of the armature. In the case of large armatures this does not matter, as they are invariably built in at least two sections for convenience in manufacture and transport.

The winding of Figs. 253 and 254 is arranged in groups of three coils each, and this armature can be divided at any point between any pair of groups without disturbing the winding at all. The diagram shows two such groups connected up.

This winding is identical with that given in Fig. 229, and its properties will be seen from Table XII. on page 189. Reference to this table shows that the armature can be divided, and also that there is *one* coil per phase per *pole pair*. Hence, for each group of coils in Fig. 254 we must have a pair of poles, and these are indicated at the top of the figure. The coils of one phase must be connected up in the same direction as in Figs. 223 and 229. The winding is a three-phase, half-coiled, double-coil, two-slot spiral winding in three ranges.

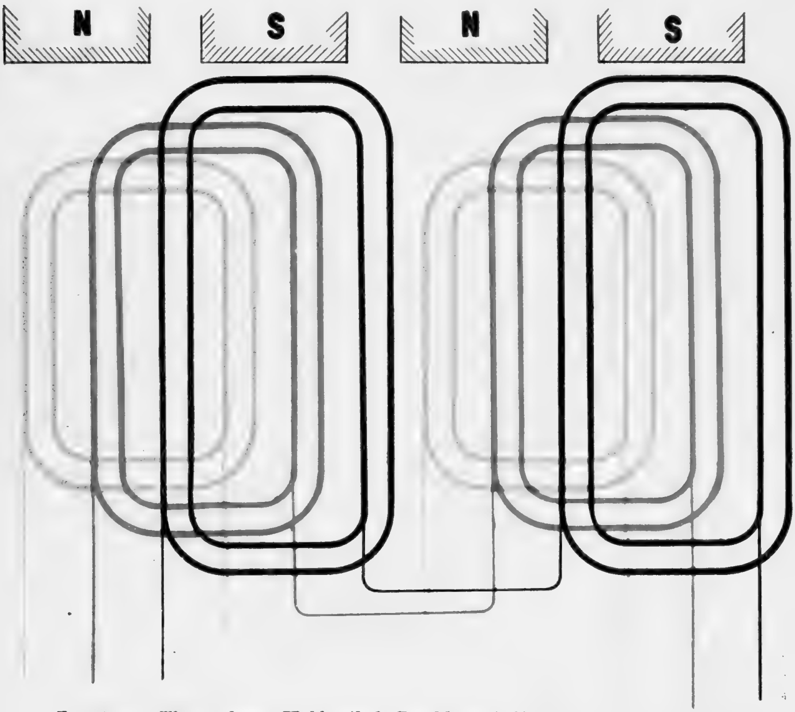


FIG. 254.—Three-phase, Half-coiled, Double-coil, Two-slot Spiral Winding in three ranges (six-phase grouping).

It is worth noting that the coils of the upper and lower ranges are exactly similar in shape. If this armature had open slots which permitted of form-wound coils, and if the ratio of gap diameter to polar pitch is sufficiently large, there need only be two kinds of formers—one for the middle range coils, and another for both the upper and lower range coils. The lower range coils have only to be placed on the armature upside down with regard to the upper range.

The other types of three-range winding (Fig. 230) have three kinds of coils, and require a corresponding number of forms.

FIG. 255.—Armature of Lahmeyer 4000 k.w. 10,000-volt Alternator. Thirty-six-pole, Three-phase, Whole-coiled, Double-coil, Four-slot Spiral Winding in three ranges.

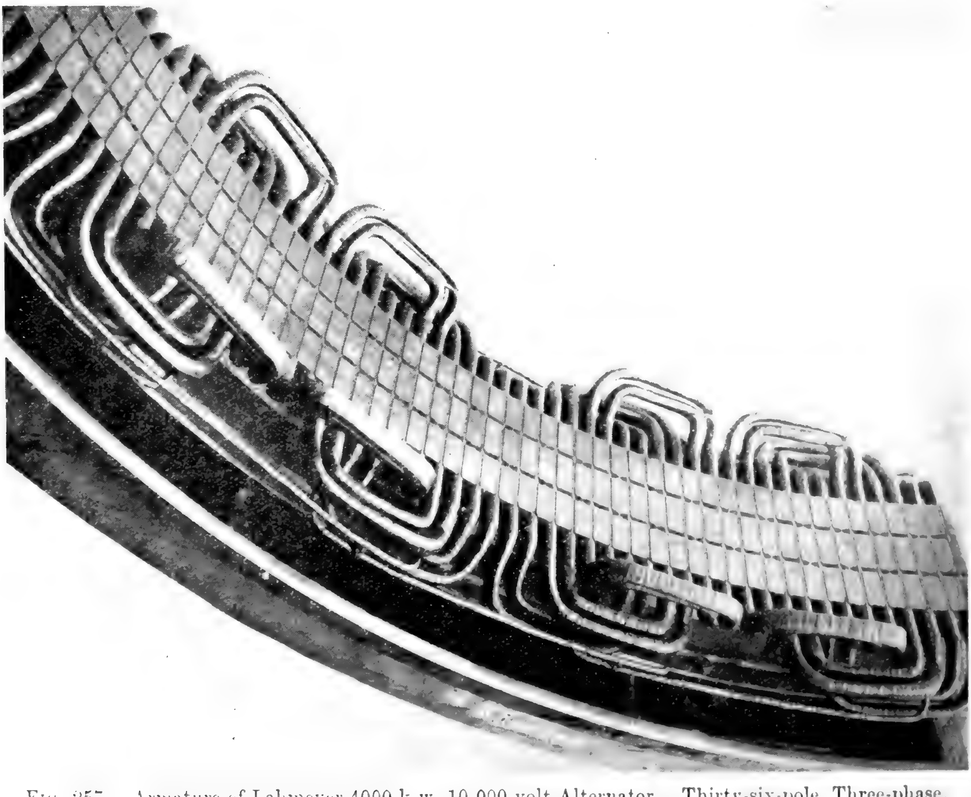


FIG. 257.—Armature of Lahmeyer 4000 k.w. 10,000-volt Alternator. Thirty-six-pole, Three-phase, Whole-coiled, Double-coil, Four-slot Spiral Winding in three ranges.

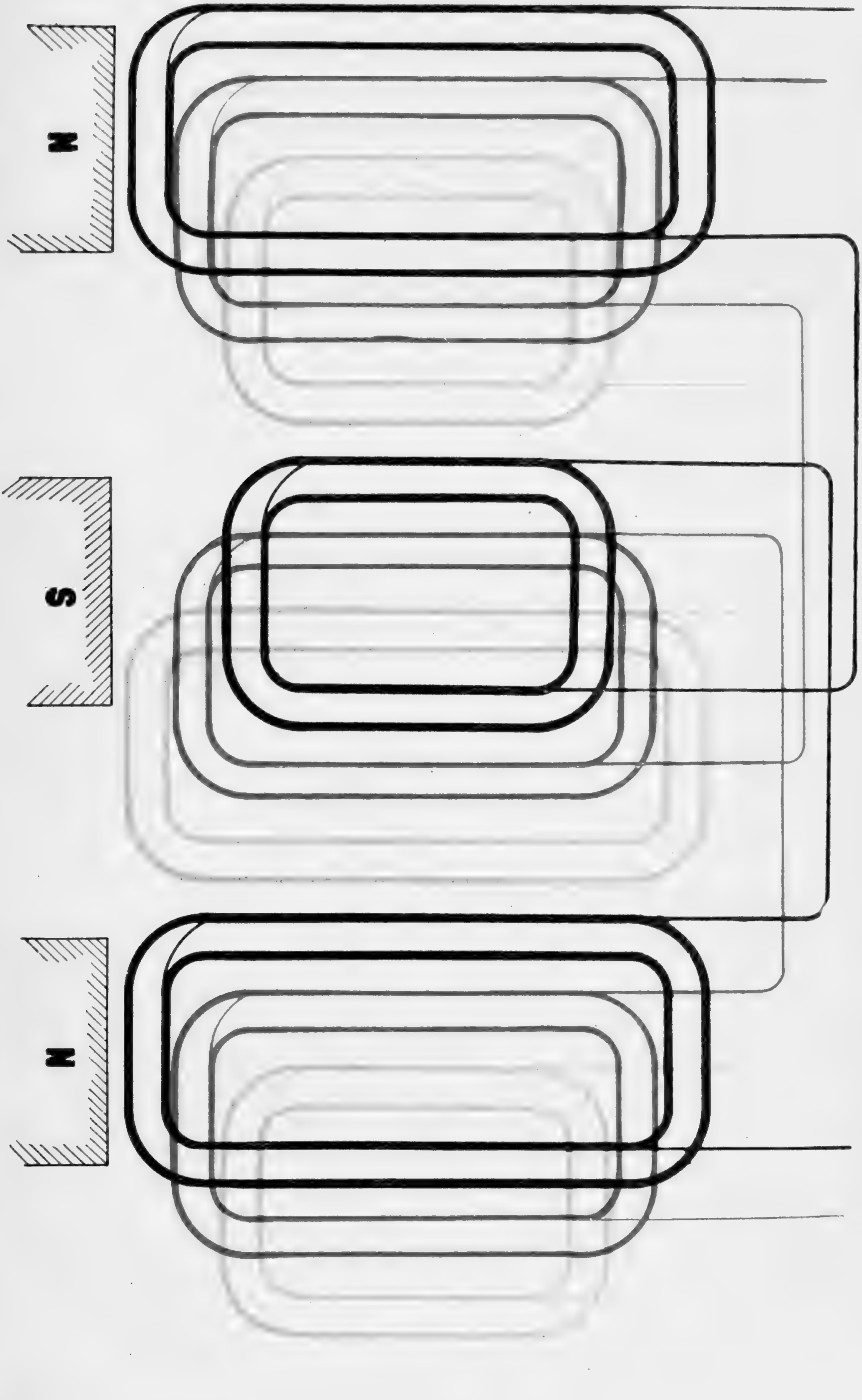


FIG. 256.—Armature Winding of Lahmeyer 4000 k.w. 10,000-volt Alternator. Thirty-six pole, Three-phase, Whole-coiled, Double-coil, Four-slot Spiral Winding in three ranges.

In three-range windings, owing to the dissimilarity of the coils in the different ranges, there is a danger of the length of the mean turn of a coil in one range differing from that of the other ranges, which renders the phases of different reactance and unbalanced.

In such a winding as Fig. 253 the coils are, however, much of the same size; but with a winding as type *e* in Fig. 230, this is not so. This is obviated by the grouping of Fig. 256, which is the diagram for the machine shown in Fig. 255. This is a 4000 k.w. 10,000 volt 36-pole three-phase alternator, of the Lahmeyer Co.

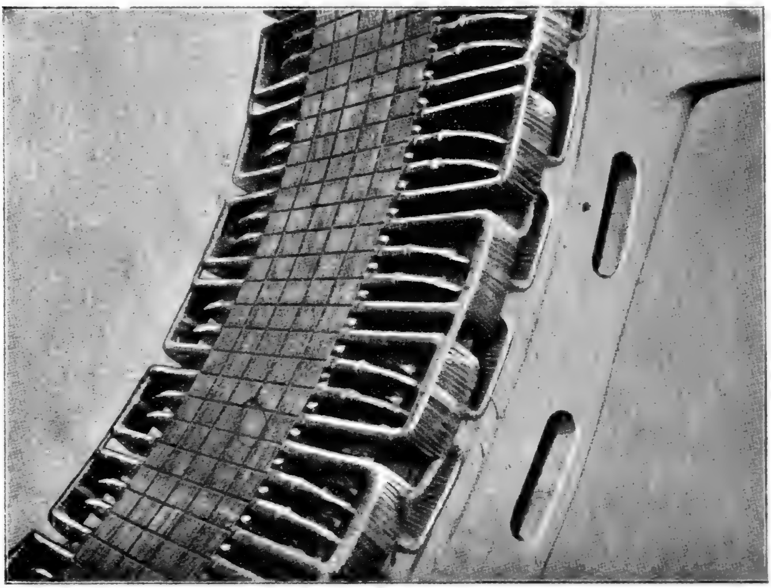


FIG. 258.—Stator Winding with similarly shaped Coils.

The title of the winding is a three-phase, whole-coiled, double-coil, four-slot spiral winding in three ranges.

A portion of the winding is shown in Fig. 257, which makes the details more clear. In this winding, as distinguished from the previous one, every alternate group of three coils is reversed so that the upper range coil of one group comes next to the upper range coil of the neighbouring group. The effect of this, as will be seen from the coloured phases in Fig. 256, is as follows:—

The coils of the red phase are all of the same and medium breadth.

The coils of the black phase are half broad and half narrow.

The coils of the blue phase are half narrow and half broad.

Thus the black and blue phases are identical, and there is less liability of the phases being unbalanced. The armature is still divisible without disturbing the coils, and a close inspection of the horizontal joints in Fig. 255 will show that a coil is located on

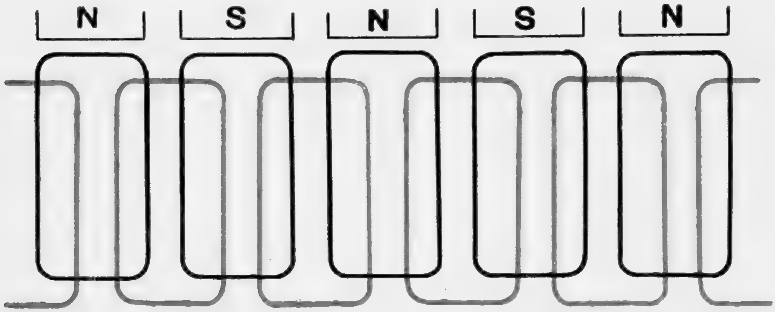


FIG. 259.—Two-phase, Whole-coiled, Single-coil, Two-slot Spiral Windings in two ranges with similar Coils.

each side of the joint, and all that is disturbed by lifting off the top half are the connectors between the coils.

The connections between the coils will be seen clearly in Fig. 257, and the length and location of these show that the connections

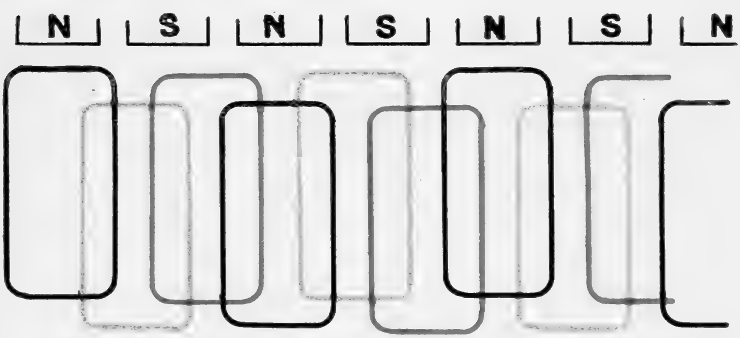


FIG. 260.—Three-phase, Half-coiled, Single-coil, Uni-slot Spiral Winding in two ranges with similar Coils.

are as drawn in the diagram of Fig. 256, where every alternate coil of each phase is reversed on its predecessor. There will thus be one pole subtending each group of three coils, and the poles will stand as shown in Fig. 256.

This winding could be connected in the same way as Fig. 254, when it would have twice the number of poles.

Fig. 258 shows a winding in which all the coils are of the

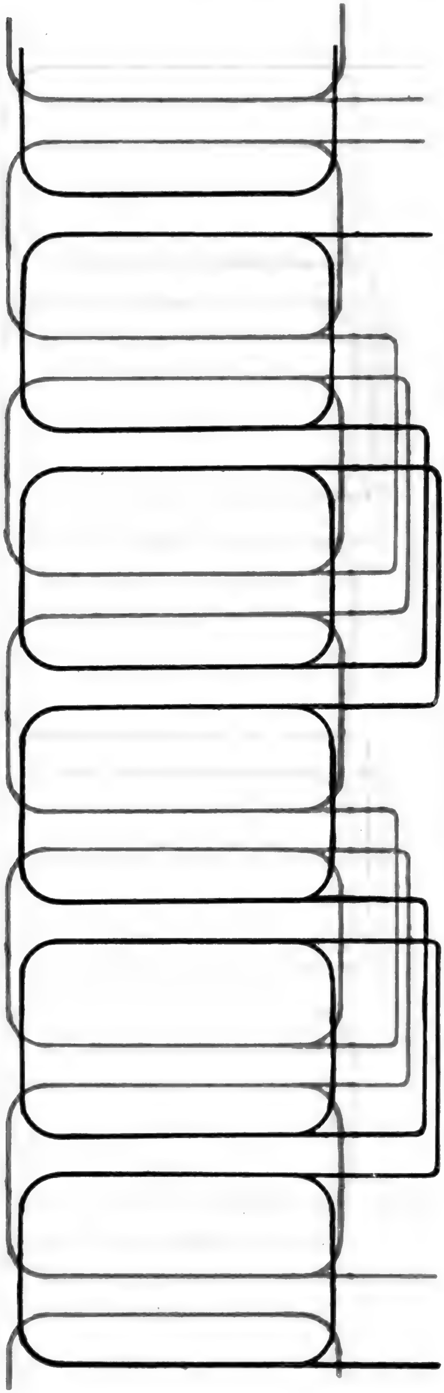


Fig. 261.—Three-phase, Whole-coiled, Single-coil, Two-slot Spiral Winding, in three ranges.

same shape, and may be made on one former. In such a winding there is more certainty of the phases being balanced. In all the previous three-range windings both ends of any single coil are in the same range, *i.e.* the ends of the coil at both ends of the armature are in either the upper, middle, or lower range, as the case may be. In the present winding, considering a single coil, at one end of the armature it is in the upper range while at the other end of the armature it is in the lower range. This will be clear, considering, for instance, the black coils only from Fig. 259, where the diagram is shown as a two-phase winding.

The two-phase winding in Fig. 259 is whole-coiled. Connected as three-phase the diagram is as shown in Fig. 260, where the winding is now changed from whole-coiled to half-coiled, and has three-quarters the number of poles, the change being made in a similar way to that in which Figs. 243 and 244 were treated on pp. 205 and 206

Before closing the subject of three-range windings, there is another type given in Fig. 261, which has *one* coil per phase *per pole pair*, which is equivalent to the windings already shown in Figs. 228 and 239, *a*, *b*, and *c*. This winding does not permit of the armature being divided, and the coils must be laid up in the manner of either of types *e* or *f* in Fig. 230 to permit of the rotating element being withdrawable. This diagram is a developed diagram of the whole-coiled winding already given in Fig. 228, and has the following title:—three-phase, whole-coiled, single-coil, two-slot spiral winding in three ranges. In Fig. 261 we have connected up the coils of the several phases and distinguished between the different ranges by three different widths of coil.

This winding possesses no superiority to any of the foregoing, except, perhaps, that the windings are more distributed, and have, consequently, less inductance and improved thermal emissivity.

Lap-coil Windings.

The difference between a lap-coil winding and a spiral-coil winding has already been shown by the two diagrams, Figs. 208 and 215, p. 171. It is not difficult to see that any of the spiral-coil windings already dealt with may be replaced by lap coils. The coil element now appears as indicated in Fig. 215.

It will be a sufficient example if we take the case of Fig. 244 and convert it into a lap-coil winding diagram. This has been done in Fig. 262, and a comparison of this diagram with fig. 244 is of interest.

This winding still retains the feature of having its twelve coils distinct from one another, and it may be connected for two-phase as in Fig. 243. The appearance of such a winding is shown in Fig. 263. This photo, however, shows part of a very large armature having a much larger number of poles than Fig. 262; but it has three slots per pole per phase, in which respect the two are identical.

The winding diagram for Fig. 263 will be the same as Fig. 262, except that it should be extended so as to have the correct number of poles. A developed diagram for a portion of the winding is given in fig. 264. The photograph of this winding in Fig. 263 shows clearly how the elements of all the coils are of equal breadth, and the manner in which the ends of the coils lie up with one another. In this case we have one conductor per slot, and the slots are semi-

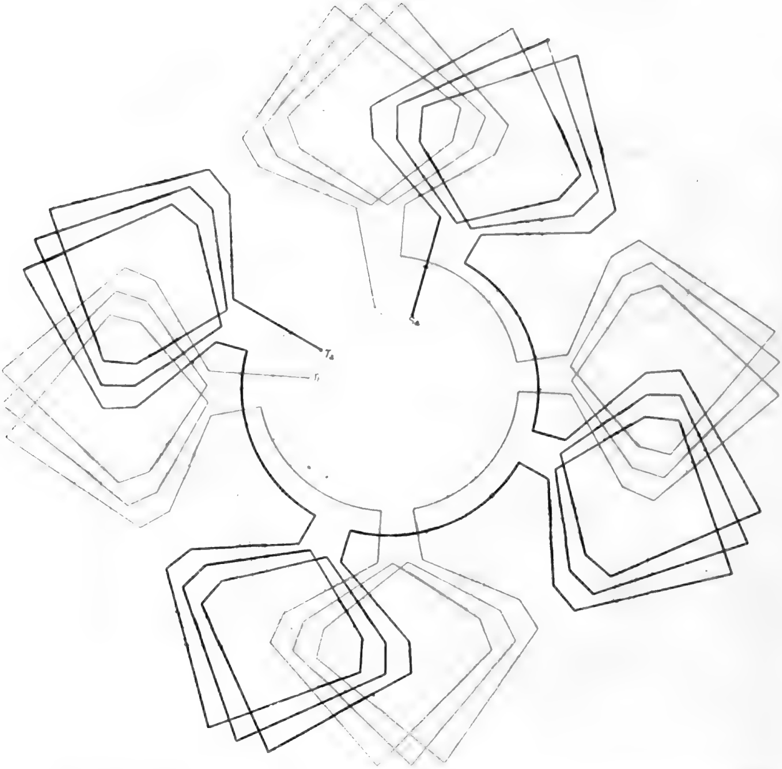


FIG. 262.—Six-pole, Three-phase, Half-coiled, Triple-coil, Three-slot Lap Winding.

FIG. 263.—Three-phase, Half-coiled, Triple-coil, Three-slot Lap Winding.

closed. Each turn is made from a continuous single piece of copper conductor slipped into place from the end of the armature.

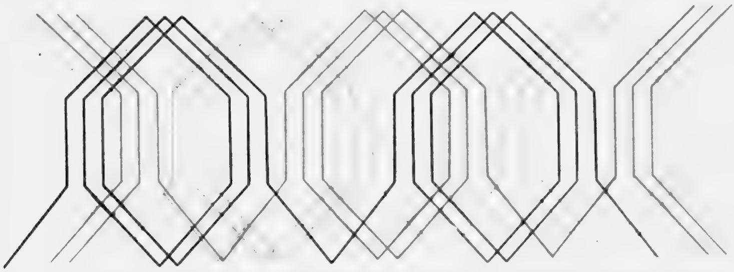


FIG. 264.—Three-phase, Half-coiled, Triple-coil, Three-slot Lap Winding.

In such cases as this it is more usual to carry out the winding as a "bar winding," where the conductors or bars are slipped into the slots from the end, and then connected up into coils by means

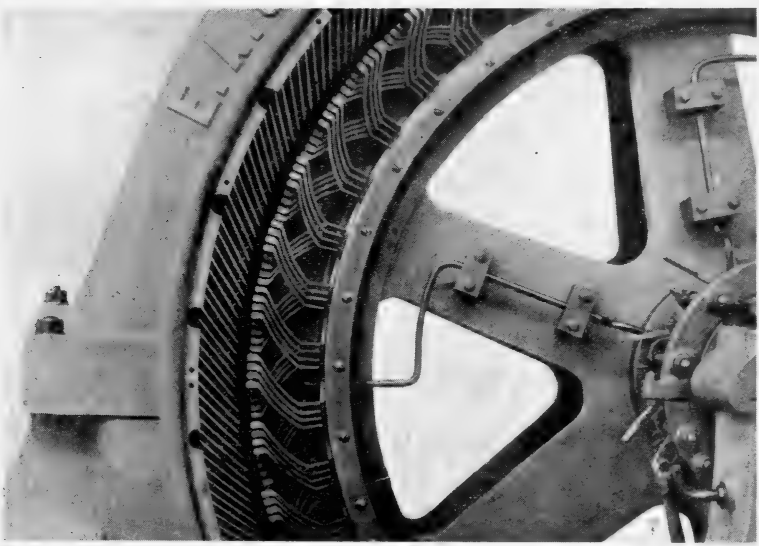


FIG. 265.—Three-phase, Half-coiled, Quadruple-coil, Four-slot Lap Winding. (Bar wound, with separate V-end Connectors.)

of separate V-end connectors all of the same size and shape. Such a bar winding is shown in Fig. 265. This having three slots per pole per phase, the diagram of Fig. 264 applies also in this case. It will be seen that the appearance of the end connectors in Fig. 265 is exactly the same as in Fig. 264.

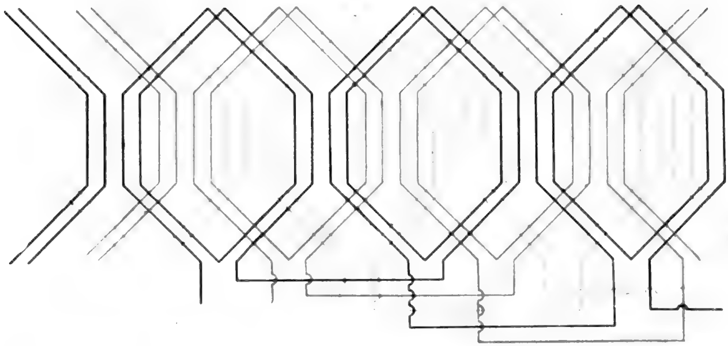


FIG. 266.—Three-phase, Whole-coiled, Double-coil, Four-slot Lap Winding.

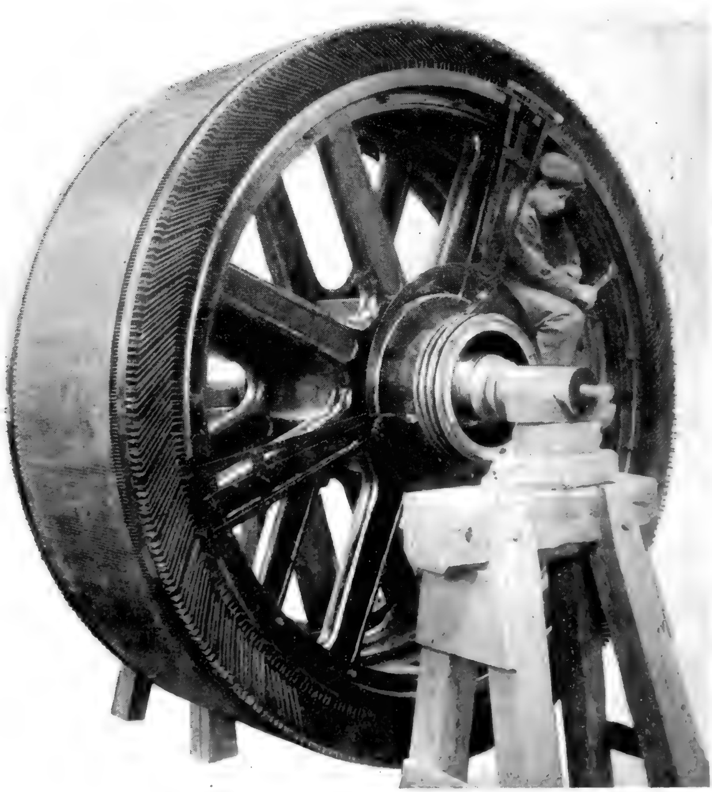


FIG. 267.—Three-phase Distributed Lap Winding (Alioth Co.).

The above windings are half-coiled; but it is easily seen that whole-coiled windings may also be lap-coil wound, and Figs. 228 and 261, for instance, could be easily so transformed.

The diagram for such a winding is shown in Fig. 266. The winding shown has four slots per pole per phase and double coils. A photograph of a winding of this type is given in Fig. 267.

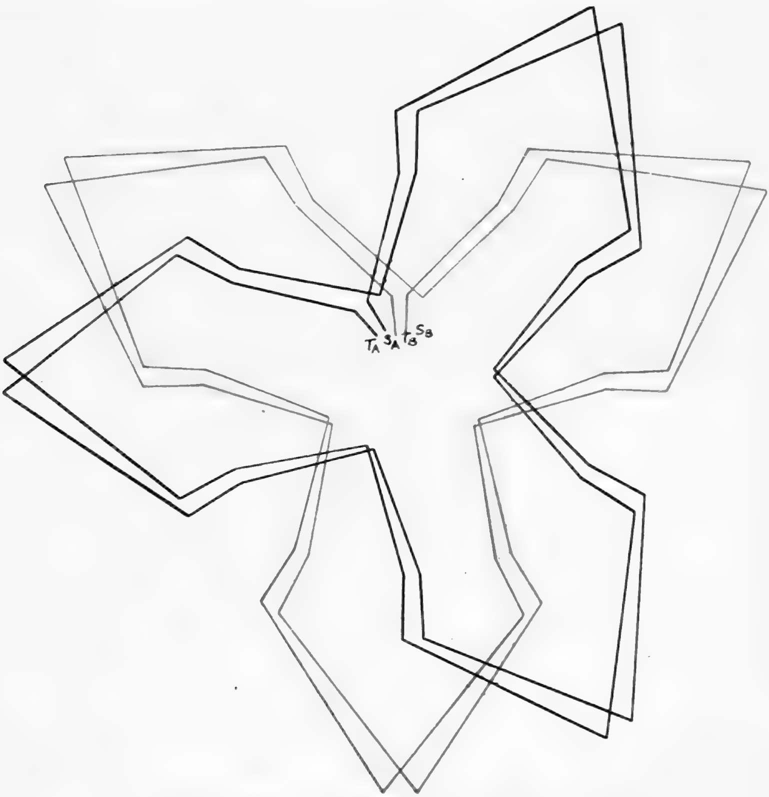


Fig. 268.—Six-pole, Two-phase, Two-slot Wave Winding.

Wave Windings.

If we refer back to Figs. 218, 219, and 220, it will be seen that, starting with conductor 1A, the winding progresses round the armature to 6A, taking in 2A, 3A, 4A, and 5A successively, and making a wave element. If, instead of conductor 1A, we had two conductors connected to two other conductors replacing 2A, we should obtain in place of Fig. 219 the two-phase diagram in Fig. 268. Fig. 220 treated in a similar manner would give a three-phase wave winding. These windings are still electrically identical with the corresponding spiral-coil and lap-coil windings; but they

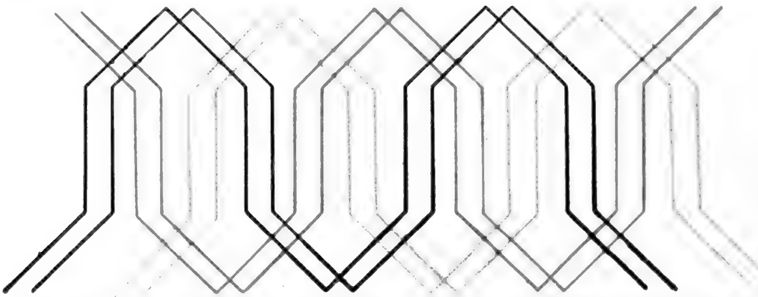


FIG. 269.—Three-phase, Two-slot Wave Winding (true Three-phase Grouping with well-distributed End Connectors)

need to be distinguished from continuous-current wave windings of the closed circuit type, which, as we shall see subsequently, are applicable to alternators.

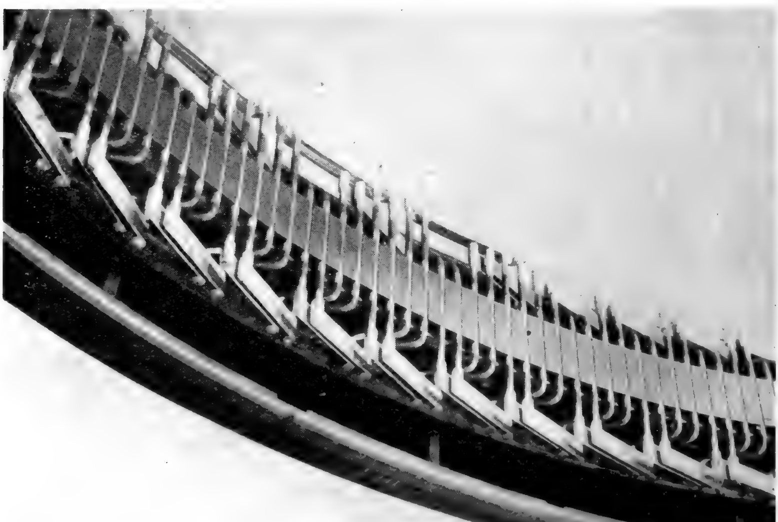


FIG. 270.—Three-phase, Two-slot Wave Winding.

If the common three-phase winding of Fig. 223 is treated in the same way, we obtain the diagram of which a developed portion is shown in Fig. 269. This is a three-phase, two-slot, wave winding.

Fig. 270 shows a photograph of a winding corresponding to this diagram. This winding is really a bar winding, but the bars are themselves cranked at one end to form half of the connector, the

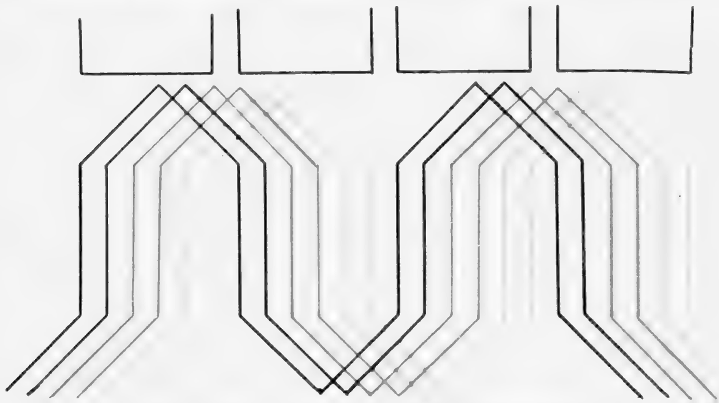


FIG. 271.—Three-phase, Two-slot Wave Winding (Six-phase Grouping with clustered End Connections).

other half of which consists of a piece of copper strip. If in Fig. 269 the red phase be reversed so that its end connectors, which were at the top of the diagram, now appear at the bottom, and

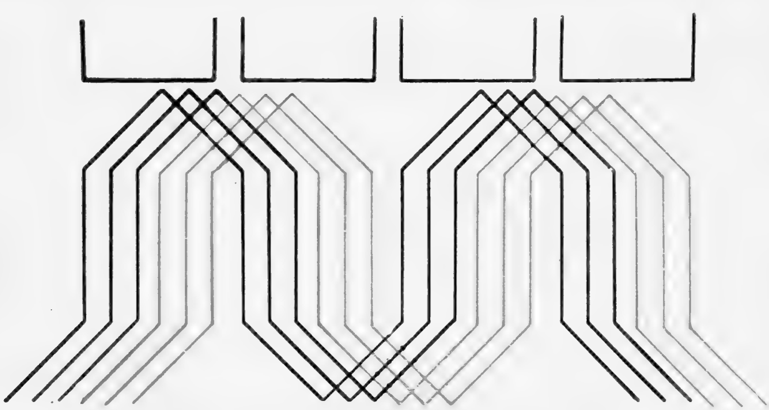


FIG. 272.—Two-phase, Three-slot Wave Winding.

vice versâ, we arrive at the winding of Fig. 271. Here the end connectors are clustered in groups, which, practically, is not so good as the evenly distributed grouping of Fig. 269. (These two cases, in fact, correspond with the coil windings of Figs. 239, *n* and *N* respectively, and a comparison is instructive.) We have, however, done this to show how Fig. 271 can be readily converted into a two-phase winding. We have six slots per pole (two per pole per phase), and in Fig. 271, under the first pole, phase A takes in conductors 1 and 2, phase B 3 and 4, and phase C 5 and 6. Fig. 272 shows the same winding as a two-phase, phase A taking in conductors 1, 2, and 3, and phase B conductors 4, 5, and 6.

The number of poles remains the same, and there are still six slots per pole; but since there are now only two phases, the number of slots per pole per phase is three, and the number of turns per phase is 3/2 times greater than in Fig. 271. We thus have a wave winding which can be used for either two or three phase. It will be remembered that earlier in this chapter (p. 205) we obtained coil windings (either spiral or lap) which had this property. The only condition is, as before, that the number of slots per pole shall be a multiple of six, for the reason that this is the smallest number divisible by both three and two.

The smallest possible number of poles is two, and hence the minimum number of slots is twelve, and the permissible numbers of slots for a wave winding common to two and three phases must be multiples of twelve, and are the same as in the case of coil windings (p. 210).

Retrogressive Wave Windings.

The wave windings heretofore described are generally more applicable to armatures with one conductor per slot carried out as bar windings. If there are two or any even number of conductors per slot, the wave winding most suitable is the retrogressive type, which is carried out in exactly the same way as a continuous-current barrel wave winding. The nature of this winding is shown by Fig. 273, which has eight poles and one slot per pole per phase, each slot containing two conductors. The two conductors are shown close together, the top one being represented by a full line and the bottom one by a dotted line. If the end connectors are all to lie up together, it is necessary to connect from the top conductor in one slot to the bottom conductor in the corresponding slot under the next pole. Thus, conductor 1 is connected to 4, 4 to 5, and so on, arriving at 16. We have now progressed once round the armature in going from the point marked A to the point marked B, but we have only taken in one-half of the conductors. To connect up this half independently, we may start at, say, conductor 14, which is a bottom conductor. It must be borne in mind that for the end connectors to lie up, the bottom conductor must be connected in the opposite direction to the top on emerging from the armature.

At the other end of the diagram the top conductors are connected to the right, and hence the bottom conductors must be

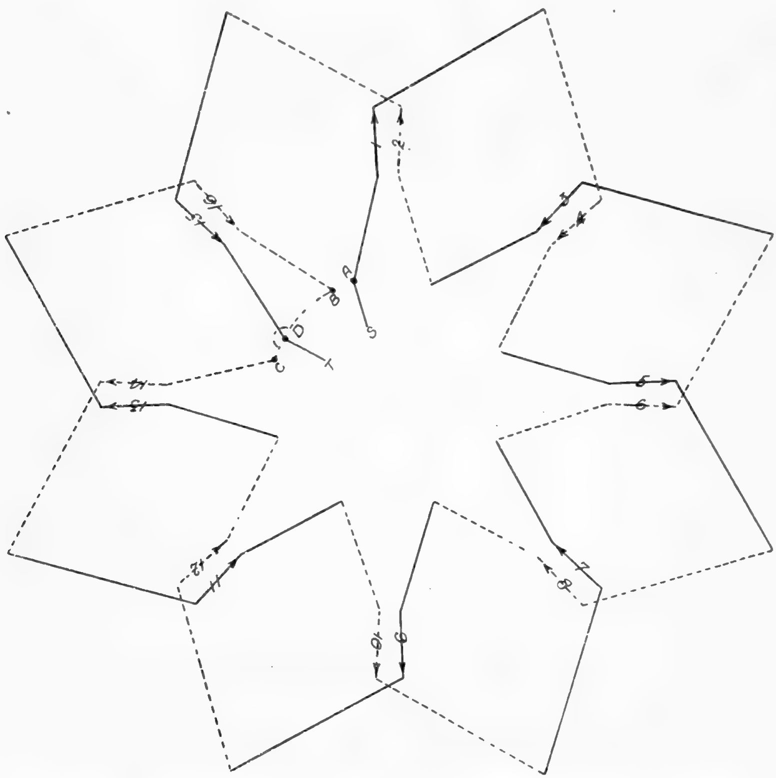


FIG. 273.—Elementary Single-phase, Uni-slot, Retrogressive Wave Winding, Two Conductors per Slot.

connected to the left, and thus conductor 14 is connected to 11, and so on round the armature, arriving at 15 after having made a complete tour in the opposite direction to that taken previously, the ends being marked C and D. An inspection of the arrowheads on the conductors, which indicate the direction of the electromotive forces, will show that, to connect these two circuits together so that the E.M.F.'s are in the same direction throughout the winding, either points B and C must be connected together, leaving A and D as terminals, or A and D must be connected together, leaving B and C as terminals.

The former of these alternatives has been taken in this case, giving the terminals marked S and T. From the winding thus connected up it may readily be seen in what sense it is retrogressive: for starting at S and following the circuit, we make a

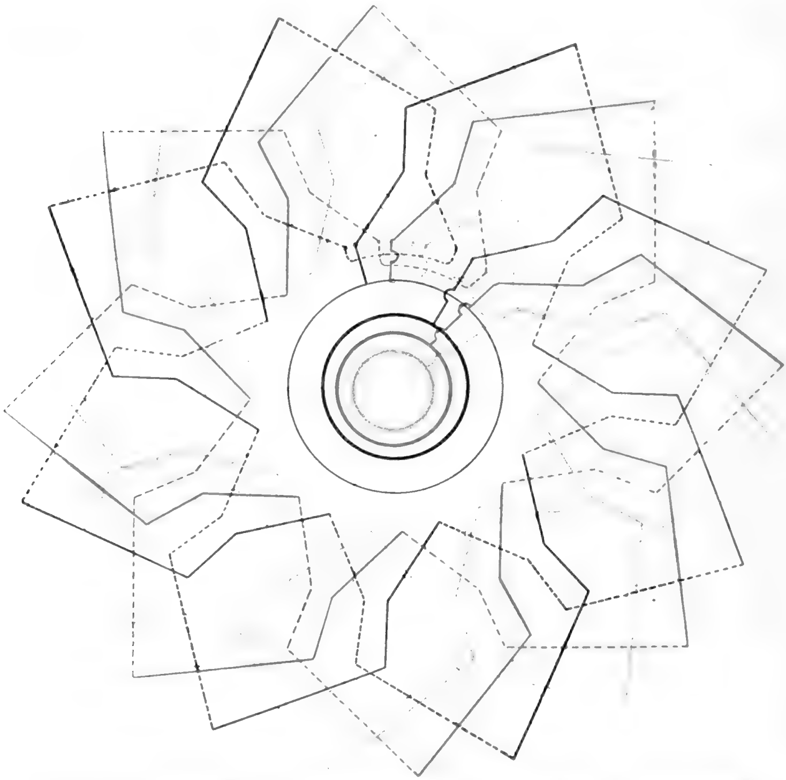


FIG. 274.—Three-phase, Uni-slot, Symmetrical, Retrogressive Wave Winding.

complete tour of the armature in one direction to the point B; and then going to point C, we make a complete tour in the reverse direction, arriving at the other terminal, T.

It is now a simple matter to complete this diagram into a three-phase eight-pole diagram by adding four more conductors (two red and two blue) under each pole, and connecting them up exactly as in Fig. 273. This amounts to superposing on Fig. 273 two additional and exactly similar phases, thus giving the diagram in Fig. 274. This winding is absolutely symmetrical, having the same number of conductors in each phase. The end connections are thoroughly evenly distributed around the circumference, the only slight irregularities occurring at the points where the terminals are taken out and where the two halves are connected.

This does not affect the appearance and construction of the winding, as is shown by the Fig. 275, which is a photograph of a wound rotating armature with this type of winding and two conductors per slot.

An example of a two-phase winding is given in Fig. 276, which relates to an eight-pole stator for an induction motor. There are

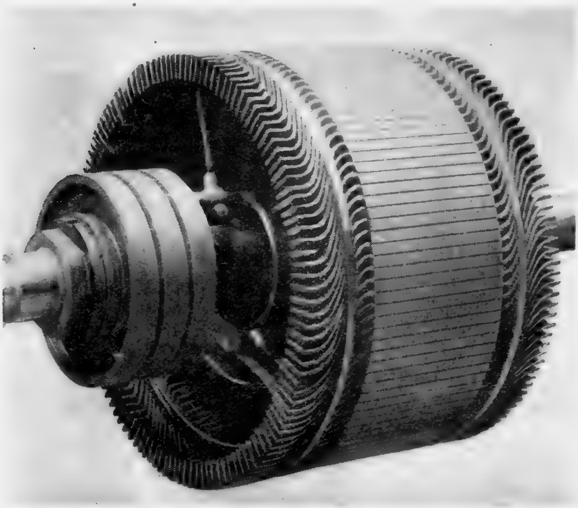


Fig. 275.—Three-phase Retrogressive Wave Winding.

eighty slots and five slots per pole per phase, with four conductors per slot.

The disadvantageous feature of this type of winding, in common with continuous-current wave windings, is that between the top and bottom conductors in the slots a pressure exists equal to half the full terminal voltage. This necessitates insulating the top conductors from the bottom conductors by an extra strip of insulation. The winding is not suitable for high voltages, but for induction motor stators of low voltage, and especially for wound rotors, it is very useful.

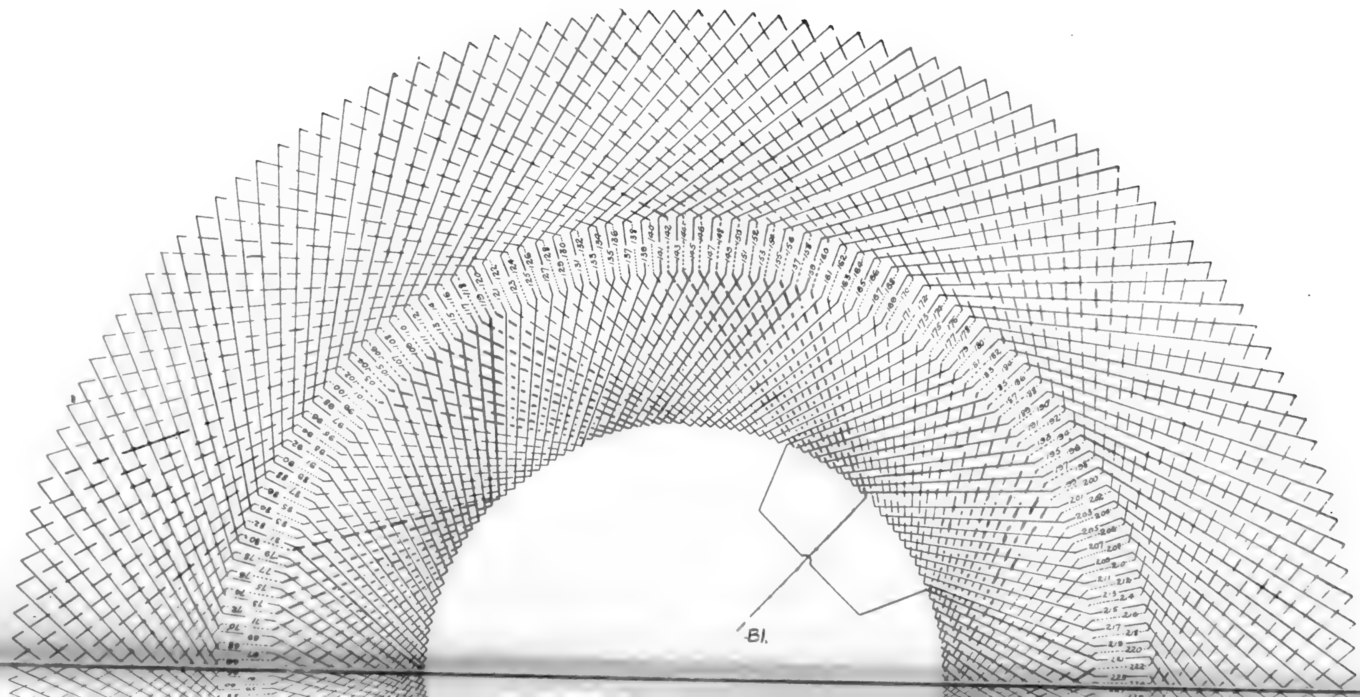
A further interesting example of the application of the retrogressive winding is afforded by Fig. 277. This winding is for a

300 k.w. 440-volt three-phase alternator. The current per phase is 460 amperes at full load, and, at a current density of 200 amperes per sq. cm., the cross section of conductor required to carry this current would be $\frac{460}{200} = 2{\cdot}3$ sq. cms. As this is a very large conductor to handle, the winding would have to be carried out as a bar winding, and preferably with straight bars and separate V-end conductors with a joint at the end of each bar, *i.e.* two joints per bar, or, as there are 480 conductors, a total of 480 joints. A large solid conductor is undesirable on account of eddy currents, and it would be better to replace the single conductor by two conductors in parallel, each of one half the cross section. The other alternative is to employ a stranded conductor, but this again is undesirable on account of the space lost in the slot due to the stranding.

If we take two conductors per slot we are at once able to carry out the winding as a retrogressive wave winding, but it will be necessary to connect the two halves of the winding in parallel, and not in series, as in Figs. 273, 274, and 276.

The diagram in Fig. 277 shows a portion of the winding (corresponding to about four poles) with the terminals brought out and the parallel connections made. The arrow-heads on the conductors and on the terminal lines indicate the relative directions of the E.M.F.'s, and the winding is connected up in the correct sense with regard to these directions. The method of parallel connecting will be more clear from Fig. 278, which shows one phase of a similar winding having only six poles but three slots per pole per phase, as in Fig. 277.

Commencing in Fig. 278 with conductor No. 1, and progressing round the winding in one direction, taking in the appropriate conductors, we arrive at conductor No. 96. Similarly for the other half of the winding, commencing at No. 6, we arrive finally at No. 19. The arrow-heads indicate the relative directions of the E.M.F.'s, and for the proper sense we must connect conductors 1 and 6 together, and also 96 and 19 together, obtaining the terminals T_1 and T_2, between which there are two equal halves of the winding in parallel. Fig. 278 should make these connections quite clear, and also the similar connections for each of the phases in Fig. 277. The advantages of this winding in this case are: (1) That the conductor is much more workable, owing to its being of smaller section; (2) the number of joints at the ends is only one half of the number in the original wave winding with one conductor


B1.

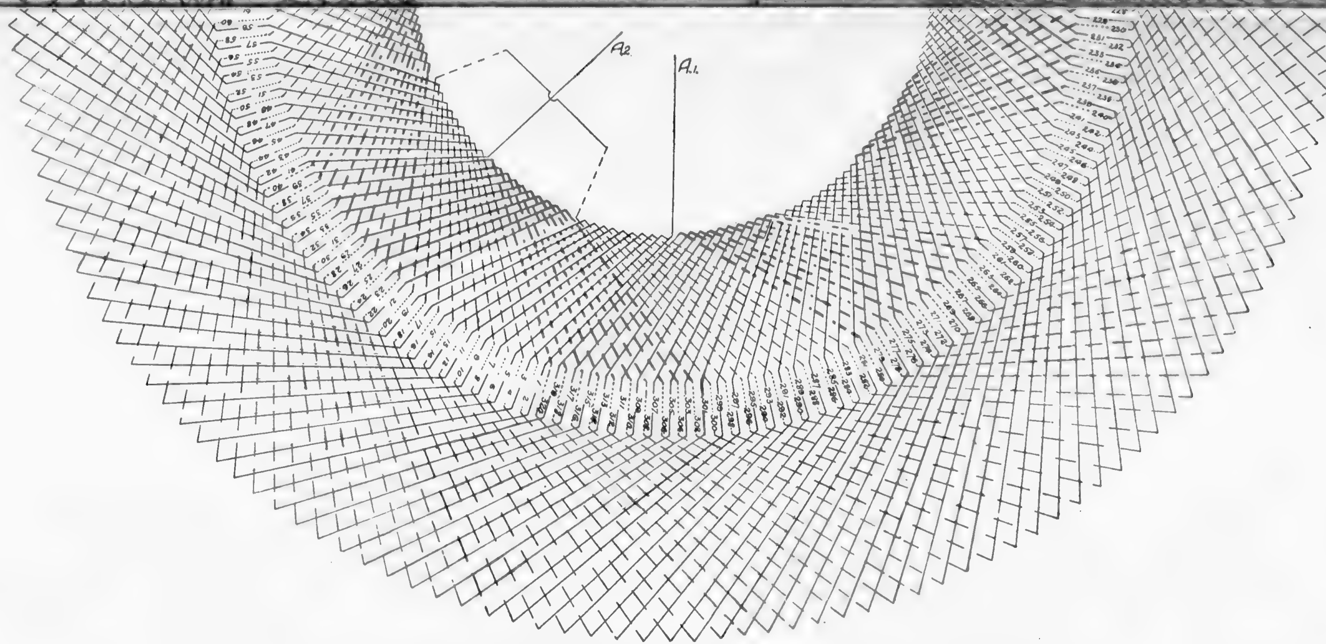


Fig. 276.—Stator Winding Diagram for Eight-pole, Two-phase Induction Motor.

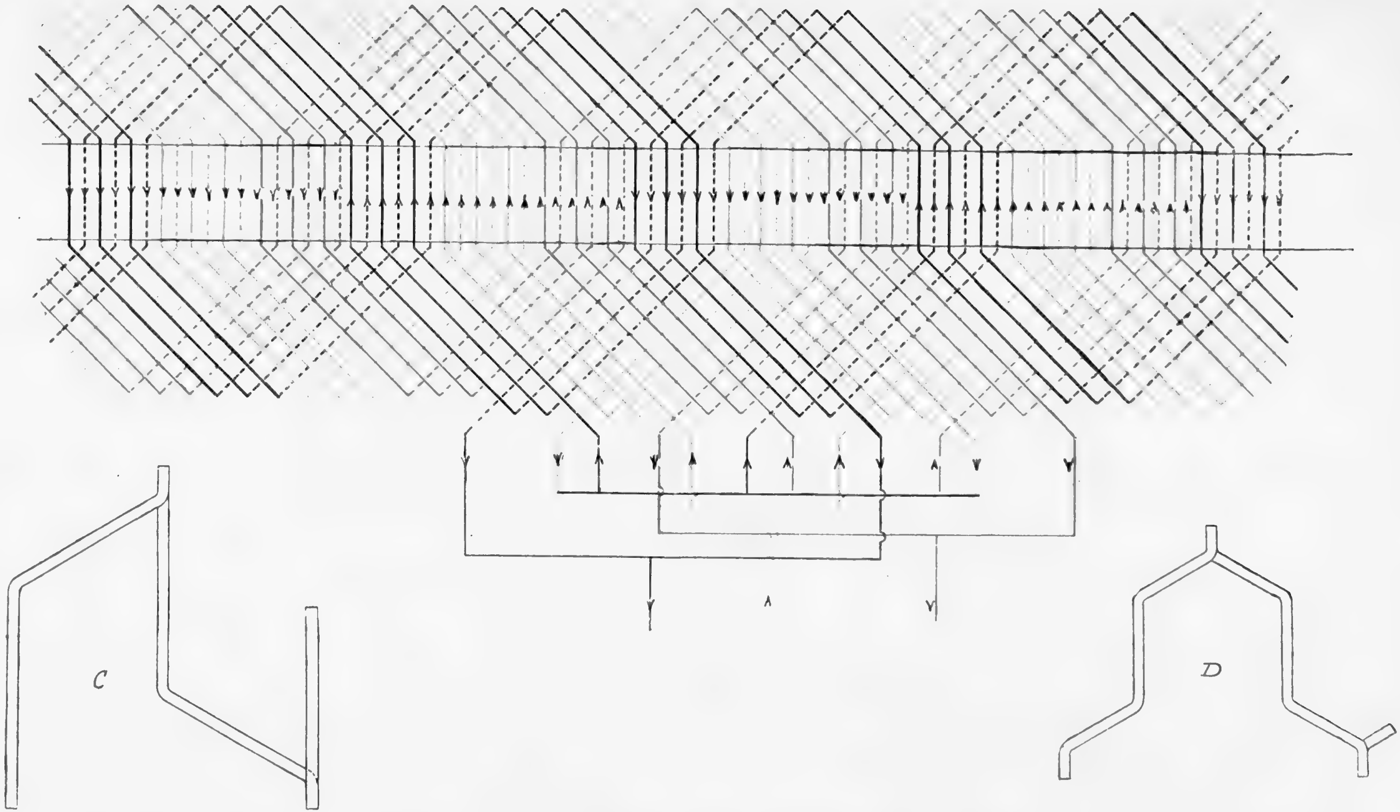


FIG. 277.—Parallel-connected, Three Slot Retrogressive Wave Winding.

per slot; (3) these joints will be easier to make than in the original wave winding, as the conductor is only half as large; (4) the scheme permits of a thoroughly distributed winding, which is better from the standpoints of heat dissipation and low inductance, and it has also a better appearance, being carried out with cylindrical barrel end connections; (5) the bars may all be shaped in the same form to either the shape shown in sketch C or D in Fig. 277.

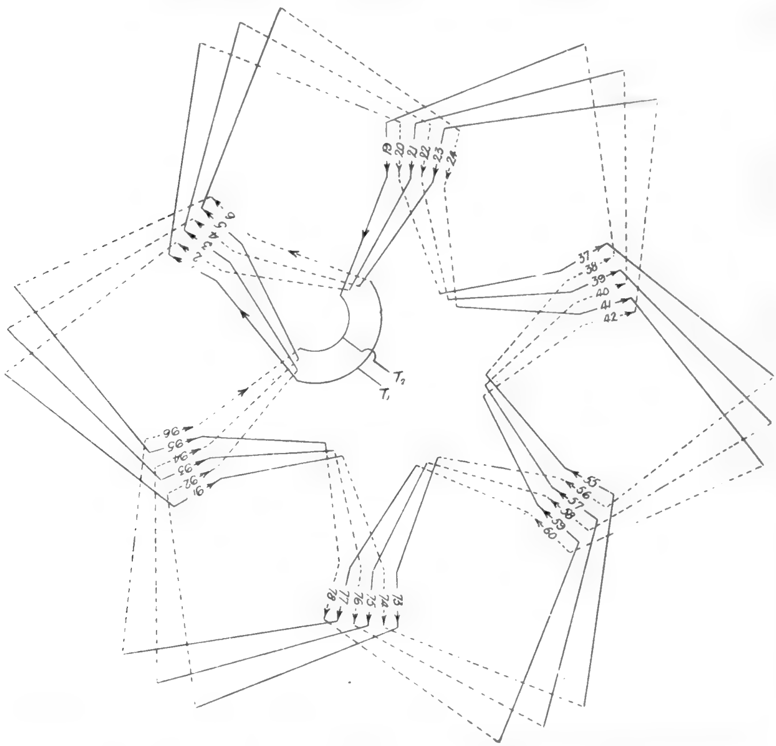


FIG. 278.—One Phase of Six-pole Parallel-connected Three-slot Wave Winding. Three Slots per Pole per Phase; two Conductors per Slot.

It will, however, be necessary with this winding to insulate the top conductor from the bottom one in the slot, as there will be a pressure between these conductors at certain points amounting to two-thirds of the voltage per phase. As this will, in this case, only amount to 170 volts, it is not serious with a low-voltage winding, and 1 mm. will be ample insulation between conductors. If the open slot is retained, the bars could be shaped as in sketch C, and dropped in at the mouth of the slots. The shape in sketch D only requires one bend per bar, and could be used either with an

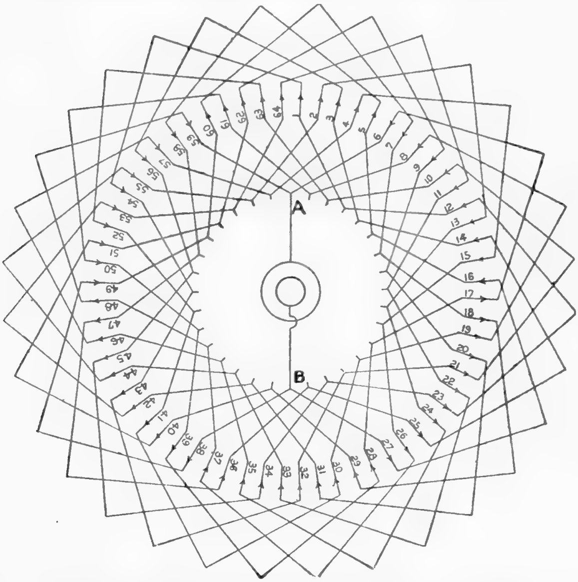


FIG 279.—Two-circuit Single Winding with Sixty-four Conductors, Six Poles, Pitch 11. Tapped for Single Phase.

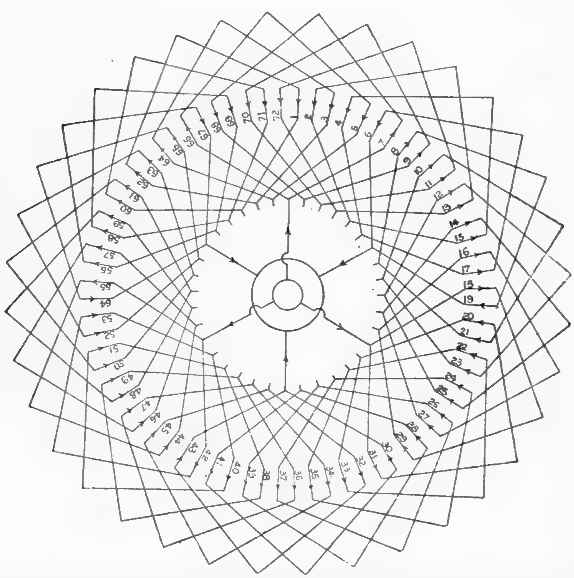


FIG. 280.—Six-circuit Single Winding with Seventy-two Conductors, Six Poles. Front Pitch 13 ; Back Pitch 11. Tapped for Single Phase.

open or semi-closed slot; in the latter case the bar would be pushed into the slot from the end.

The question of an open or closed slot is largely one of experience in manufacture, and either can be used, but if the semi-closed slot is used the bars must be shaped as sketch D.

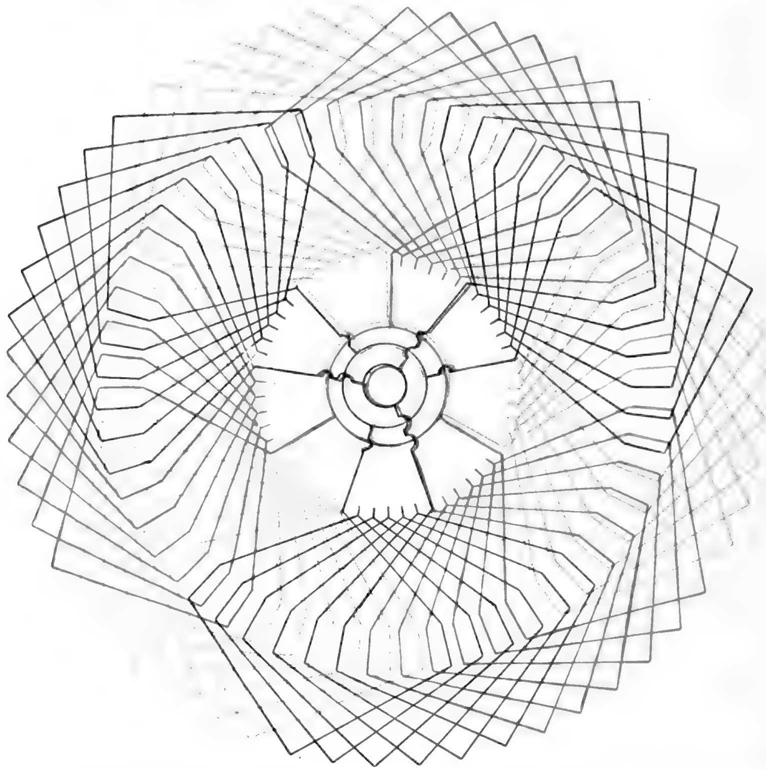


Fig. 281.—Winding for a Three-phase Rotary Converter, Six-circuit Single-winding with 108 Conductors, Six Poles. Front Pitch 19, Back Pitch, 17.

II.—CLOSED-CIRCUIT WINDINGS.

As was stated at the beginning of this chapter (p. 163), any continuous-current winding can in general be employed for alternating current work, by dispensing with the commutator and tapping the windings at a few suitable points and connecting from these points to the slip rings or stator terminals.

To convert a two-circuit (or wave) winding into a single-phase alternating current winding it is necessary to tap it at only two points, each connected to a collector ring. With a multiple circuit winding there must be one tapping for each collector ring per pair of poles, *i.e.* the total number of tappings is equal to the number of poles. Taking, for example, the two-circuit single-winding shown in Fig. 279, which has 6 poles, 64 conductors, and pitch 11, the winding is tapped at some point A to one collector ring, and then,

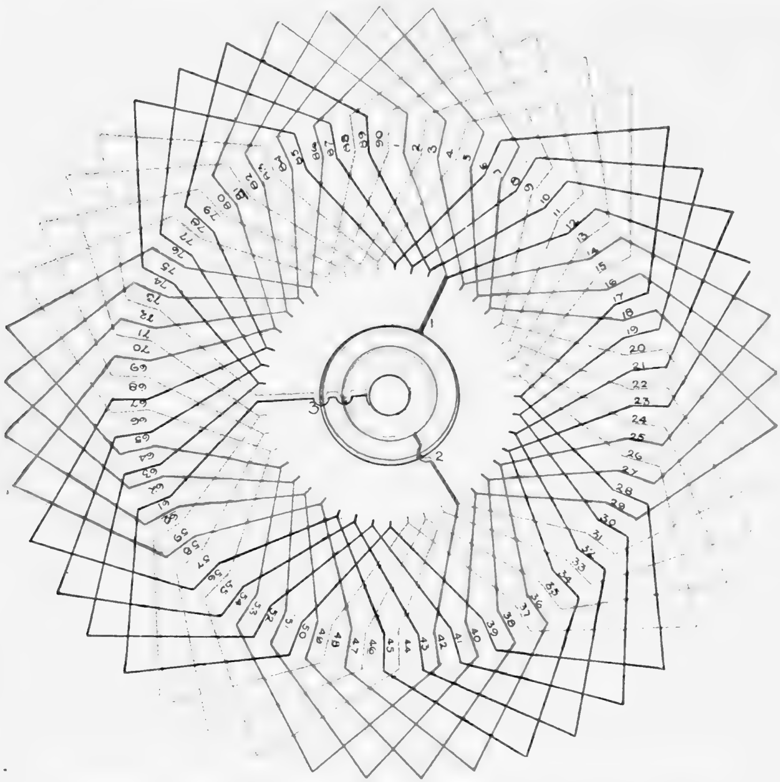


Fig. 282.—Winding for a Three-phase Rotary Converter, Two-circuit Single-winding with Ninety Conductors, Eight Poles. Pitch 11.

after tracing round one half of the conductors, a tap is taken out at point B to the other collector ring.

If the winding be doubly re-entrant there must be two taps at neighbouring points to each ring; that is, one tap per ring for each re-entrancy. Corresponding rules apply for other multiply re-entrant windings.

As an example of a multiple-circuit winding, Fig. 280 shows a six-circuit single winding with 72 conductors and 6 poles.

In tapping this winding for single-phase alternating current, we may first connect the lead from conductor No. 7 to one collector ring, then we progress around the winding until we have taken in one-sixth of the total number of conductors, *i.e.* twelve, which occurs when we reach conductor No. 31, at which point another tapping is made to the same collector ring.

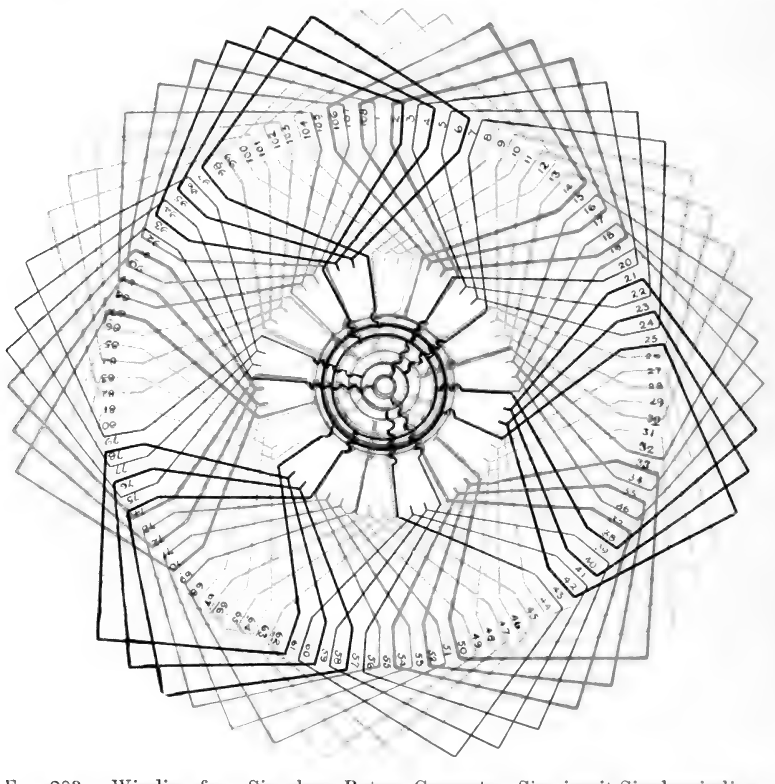


FIG. 283.—Winding for a Six-phase Rotary Converter, Six-circuit Single-winding with 108 Conductors, Six Poles. Pitch: Front, 19; Back, 17.

After taking in twelve other conductors, another tapping is brought out after having traversed conductor No. 55. In progressively taking in one-sixth of the conductors we pass over one-third of the periphery, or a distance of twice the pole pitch. Thus if we take one tap out at conductor No. 7, the next tap to the same ring occurs at conductor No. 31, and the pitch of conductors between one tapping and the next is 24, or $\frac{72}{6} \times 2$, or, generally, twice the number of conductors per pole. The same applies to the tappings to the other ring, but the first tapping must be brought out from a conductor similarly situated to conductor No. 7, but under the next adjacent pole. This will be No. 19, as there are twelve conductors per pole. Thus we take tappings to the second ring from conductors 19, 43, and 67.

It is clear that as both of the above windings are

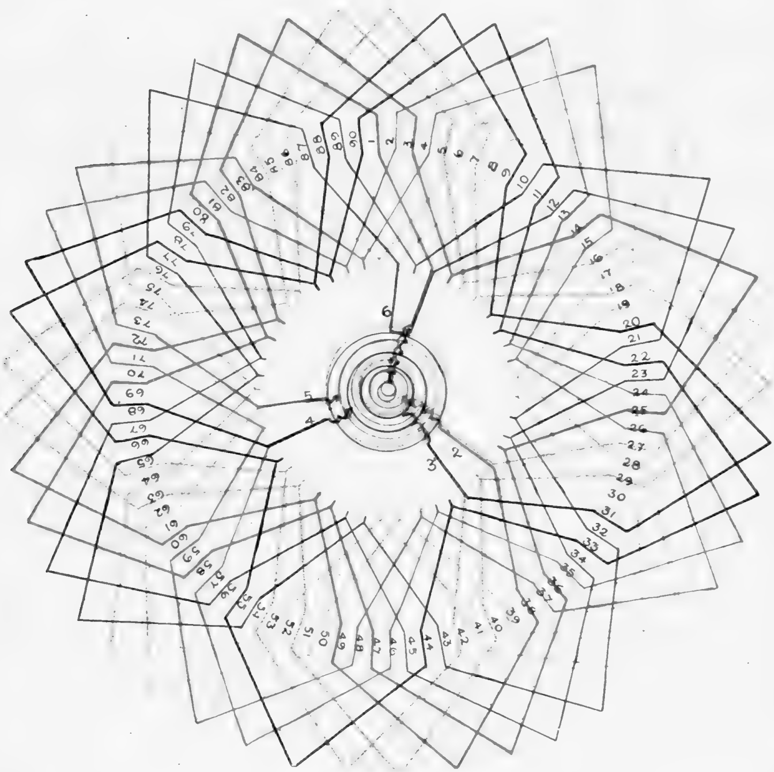


Fig. 284.—Winding for a Six-phase Rotary Converter, Two-circuit Single-winding with Ninety Conductors, Eight Poles. Pitch 11.

essentially continuous-current windings and are capable of being tapped for alternating current, they are applicable at once to rotary converter armatures, if in addition to the collector rings a commutator is added connected at the proper points, which are shown with short lines attached in Figs. 279 and 280. The windings which we shall now proceed to consider will be referred to as rotary converter windings, and it will be borne in mind that by omitting the commutator they are at once alternating-current windings only.

The carrying out of these windings, and the laws which govern them, are the same as for continuous-current windings. These have been dealt with in Chapter VIII. It will therefore suffice if we give a few examples of typical polyphase rotary converter windings. For three-phase multiple-circuit simplex windings there are three sections of winding per pair of poles. In two-circuit windings there are three sections per winding independently of the number of poles.

Thus a six-pole machine with a six-circuit simplex winding has $\frac{6}{2} \times 3 = 9$ sections, *i.e.* three per pair of poles.

To tap such a winding for three-phase, leads are taken out to the collector rings at equal ninths through the armature from beginning to end.

Fig. 281 shows such a winding having 108 conductors. The portion of the winding lying within one pair of poles is divided into three sections coloured black, red, and blue, and taps are taken out to the three collector rings at the junctions of these sections, giving nine taps in all.

Had the winding been a two-circuit single winding there would have been only three sections, and taps would have been required at equal thirds around the armature.

Fig. 282 illustrates an eight-pole two-circuit winding with 90 conductors and a winding pitch of 11. Tappings are brought to the collector rings from the leads to the three conductors numbered 1, 31, and 61. The phases when distinguished by colouring, stand as in Fig. 282.

The distinctive feature which will be noticed from Figs. 281 and 282 is the overlapping of the phases in three-phase closed circuit windings. This is clearly brought out by the colours. Thus any portion of the armature periphery carries conductors belonging to two different phases, such conductors occurring in the same slots. For instance, in Fig. 282 the portion of the armature from conductor 1 to 6 carries red and blue conductors, from 7 to 13 black and blue, and so on round the whole armature, the conductors of one phase being distributed over two-thirds of the periphery. This does not occur with six-phase windings, and as this feature results in a less output for the three-phase machine, the six-phase rotary converter is coming to be more commonly used.

The positions of tappings for six-phase windings are shown in

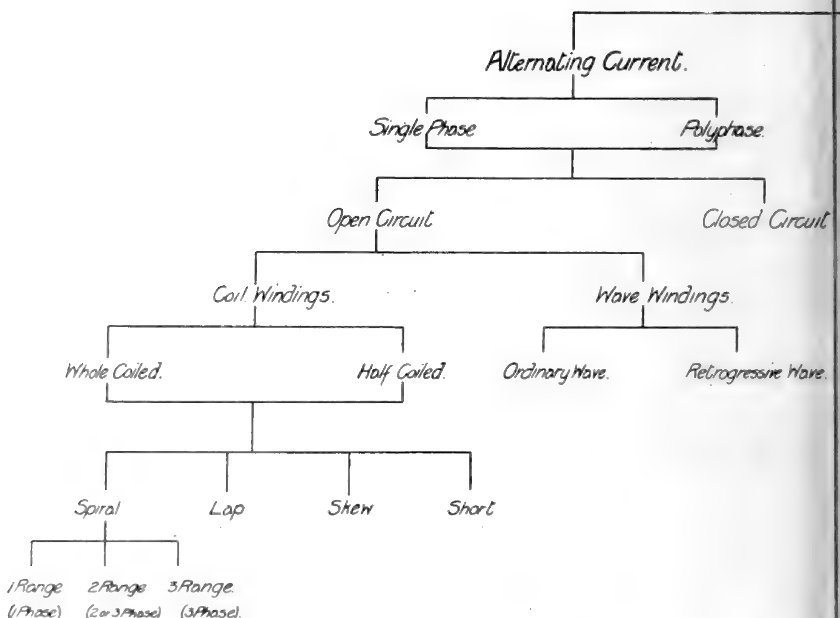
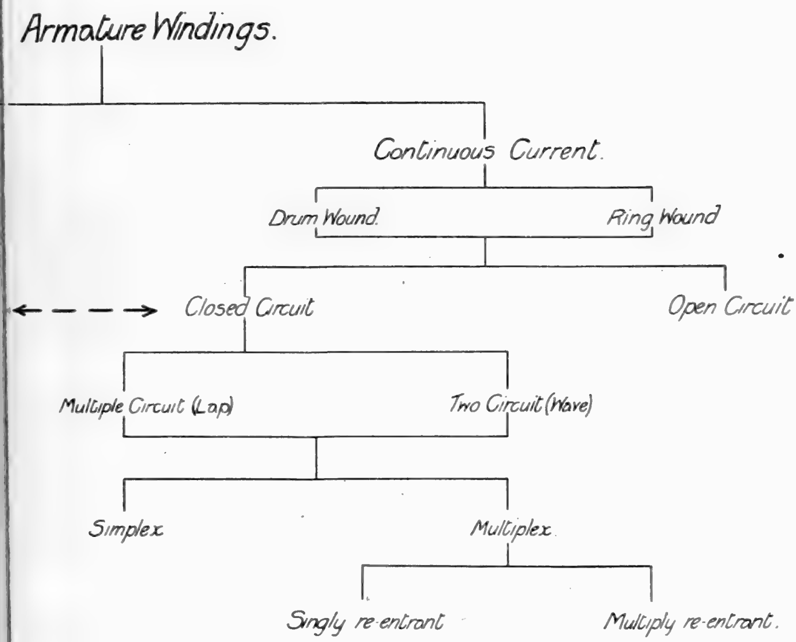


Table showing the Nomenclature, Classificat



...and Derivation of Armature Winding.

Figs. 283 and 284, which are the same windings as Figs. 281 and 282, but tapped for six-phase. The winding has to be divided into twice as many sections as for three-phase. Thus, the six-circuit winding which was divided into nine sections in Fig. 281 is now divided into eighteen sections in Fig. 283, the conductors belonging to the different phases being distinguished by colours. It will be seen from Figs. 283 and 284 that each part of the armature periphery is now occupied by conductors belonging to one phase, and there is no overlapping as in Figs. 281 and 282.

CHAPTER X

THE INSULATING OF ARMATURE CONDUCTORS[1]

In order to obtain a high "space factor" in armature slots, it is essential not only to select the very best of materials for the insulation of the groups of conductors, but careful attention must also be given to the order of their arrangement, so that those materials most suitable for withstanding mechanical strains shall be so disposed as to shield the mechanically more delicate, but dielectrically stronger materials. We must consider the reasons leading to the use of particular materials in various cases.

It has for many grades of work been found preferable in practice that a tough fibrous material, suitably treated to render it moisture-proof, should come next to the iron walls of the slot, in order to protect from mechanical injuries the conductors and their high-grade insulating wrappings. Nevertheless, where motors are manufactured in quantities, the slot lining is often dispensed with, and the form-wound coil, after being hydraulically compressed, is forced into the unlined slot.

The following materials have been employed for slot linings. They are arranged in the order of their toughness:—

Horn Fibre.
Leatheroid.
Presspahn.
Red Rope Paper, and
Manilla Paper.

These and similar materials may be obtained of almost any thickness. It is generally preferable to use several layers of thin material in making up a slot lining of a required thickness. Thus, for example, sheets of presspahn, each 0·25 mm. thick, used in two or three layers, are far more flexible and give a somewhat higher total disruptive strength than single sheets of equivalent thickness.

[1] Part of the material contained in this chapter is drawn from Chap. XIV. of *The Insulation of Electric Machines* (Turner & Hobart), to which the reader is referred for a full treatment of the subject.

There is less danger of cracking the material at the bends, and if faults exist in the component sheets, the danger of a superposition of these faults is less the greater the number of sheets. Each sheet may also be more thoroughly dried out the thinner it is. One also avoids the necessity of keeping in stock a large number of different thicknesses

Horn fibre ranks first, both in mechanical and in disruptive strength, but does not run very uniform in thickness. It is also relatively expensive.

Presspahn ranks first in uniformity of thickness and in surface smoothness; it is tough mechanically, and has high disruptive strength.

Red rope paper and manilla paper are cheap, and are widely used for slot linings, but care must be taken to test the quality. Manilla paper is preferable.

When wood is used in armature construction, it must be dried with the greatest care and made waterproof by suitable treatment. It is often used for the retaining wedges for the slot conductors, but has the disadvantage that, when so employed, it will, in the interests of mechanical strength, require more space than is necessary by other arrangements and materials. It obstructs the emission of heat from the conductors. It is also difficult to avoid warping and cracking. It involves the use of more expensive punches and dies. In general it may be said that the use of wood in armature slots is to be avoided. Formerly it was employed to a great extent. It is preferable to let the insulated armature coils come directly to the surface and be held in place by binding bands.

Great care must be exercised with all slot-lining insulations to subject them to thorough drying and waterproofing processes. A very effective process consists in prolonged immersion in hot linseed oil. When recourse must be had to the use of wood for slot wedges, great care should be employed in the selection and treatment of the wood. It should be of hard, fine grain, as, for example, maple or teak. It must be cut with the grain, and must be free from knots and irregularities of all kinds. It must be thoroughly seasoned and dried. The ultimate drying should be in a vacuum oven, and after being taken from the oven it should, while still hot, be immersed in double-boiled linseed oil, and left there for from twelve to twenty-four hours, the temperature being maintained near the boiling-point. The wood thus becomes thoroughly impregnated, making it moisture-proof and improving its insulating qualities.

Figs. 285 and 286 are instances of the preferable design for armature slots in which wedges are dispensed with. The use of wooden wedges is at present coming to be restricted to the external stators of induction motors with open slots, for in this case, use cannot, of course, be made of binding wires. Fig. 287 gives an instance of such a slot.

Mica and micanite should only be employed for slot linings in high-voltage machines. Pertinax and micarta and presspahn-mica are all good alternatives in suitable cases.

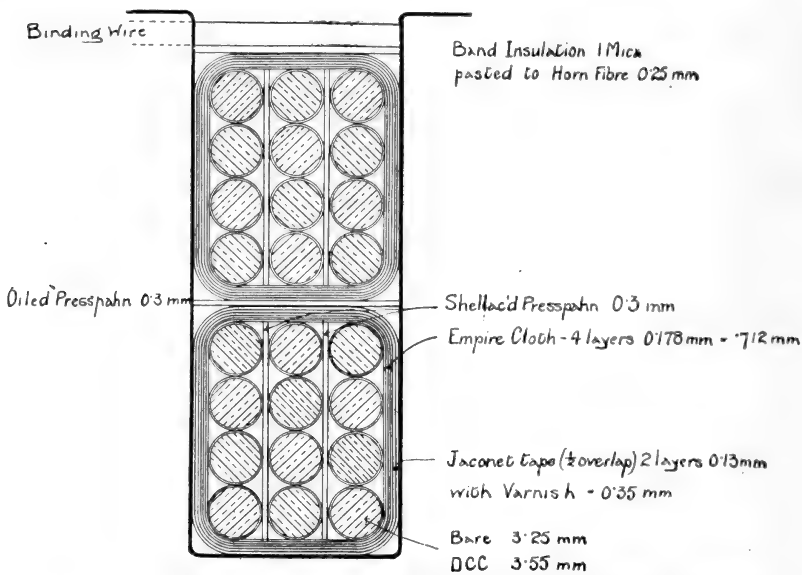


FIG. 285.—Section through Slot of Wire-wound Continuous-current Armature.

For materials to be employed in binding the conductors together in groups, and for the wrapping for armature bars, one or more of the materials given in the following list may be employed:—

- Cotton tape (sometimes known as "jaconet" tape, and generally 0·13 mm. thick).
- Varnished cambric.
- Manilla paper, impregnated with insulating varnish.
- Oiled unbleached cotton.
- Mica paper.

From this variety a suitable choice will ensure good results if care is used in the preparation and application. A few examples from practice will be of service.

Insulation Specification for 500-Volt Tramway Motor Armature Slots.

The conductors are first finely spun with a double cotton covering. This, of course, is generally done by the firm supplying the copper wires.

The wound coils are dried for three hours in a vacuum oven at 90° C., and are then impregnated with a good and preferably plastic insulating varnish to render them moisture-proof.

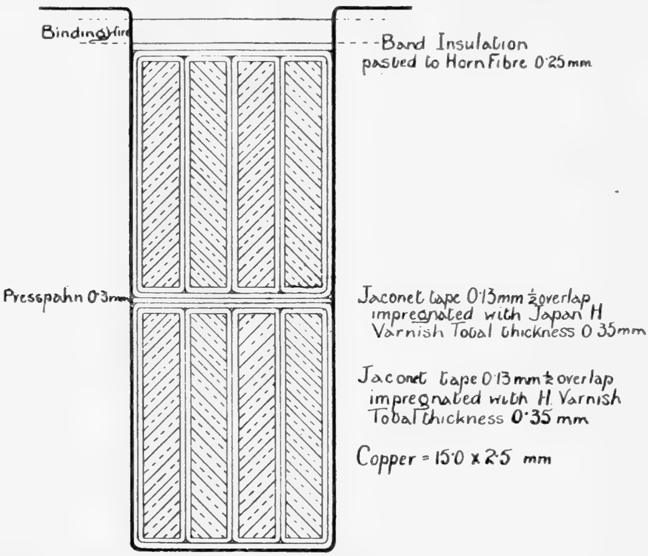


FIG. 286.—Section through Slot of Strip-Wound Continuous-current Armature.

In making up the compound coil, pieces of very thin shellac'd presspahn[1] are placed between the component sections. The two straight sides (*i.e.* the slot portion) are then placed in a steam or electrically heated mould, thus compressing the whole group of conductors into a solid compact form.

The slot portion is then wrapped over with from two to four layers of varnished cambric, and then the whole coil is served with "jaconet" tape (cotton tape), 0·13 mm. thick and 16 mm. wide, wound with half overlap.

[1] Shellac'd presspahn has the advantage for this purpose that the shellac is pressed laterally out between the wires, filling up the interstices and cementing the whole into one compact mass. There is not enough shellac present to be harmful.

The coil must next be dried in a vacuum oven and dipped twice in a plastic varnish, and subsequent to each dipping it should be dried for three hours in a vacuum oven at 90° C.

After dipping the slot portion in hot paraffin wax, to protect it against possible abrasion during assembling, the coil is ready to be assembled on the armature. The section through this coil assembled in the slot is shown in Fig. 285.

When completely assembled on the armature core and bound,

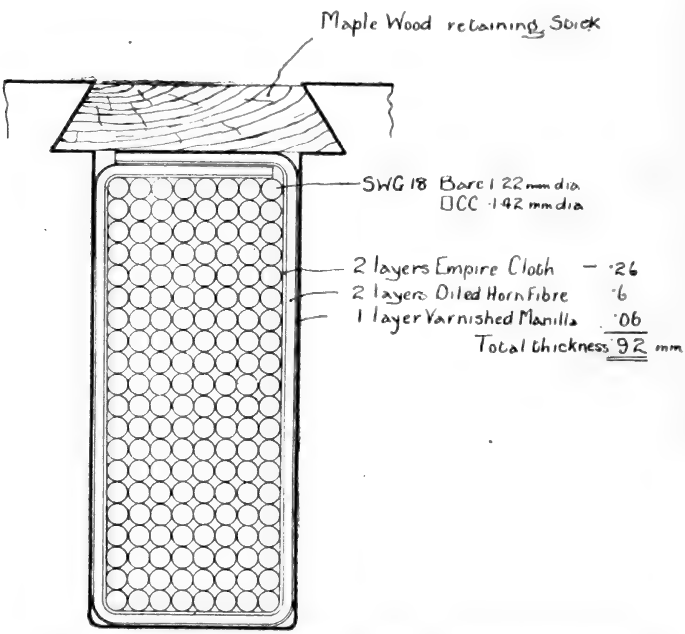


FIG. 287.—Section through wide open Slot of Stationary Armature.

such a winding should stand for one minute at 20° C. the application of at least 3500 R.M.S. volts from copper to core.

In Fig. 286 is shown the slot arrangement for a strip winding with 8 conductors per slot, placed 4 wide and 2 deep. Such a 500-volt strip winding should be tested with at least 3500 volts when connected and completed.

The strips, after being served with "jaconet" tape and thoroughly dried, must be made waterproof by impregnating the tape with some good and preferably plastic varnish. After the application of each coat of varnish, the strips must be baked for three hours in a vacuum oven at 90° C.

The following is a concise outline of a good treatment for insulating form-wound coils. It presupposes that one of the permanently plastic varieties of varnish is employed. Such varnishes have now been placed on the market by several firms.

1. Wind the coils on a former to the required shape (see Chapter XI.).

2. Place the form-wound coils (either double cotton covered or braided) in the baking oven, which should preferably be of the vacuum type, for one hour at 90° C.

3. Immediately on removing from the baking oven, while the coils are still hot, they should be immersed in insulating varnish and kept so immersed until air bubbles cease to rise.

4. Return the coils to a baking oven, now filled with air instead of being exhausted, and bake for ten to twelve hours at 90° C.

5. Tape the coils with impregnated tape, applying it with one-third overlap.

The tape may be prepared and impregnated in the following manner:—

(*a*) Dish the rolls of tape by pushing their centres outward, rendering them concave in order to expose a maximum of surface.

(*b*) String these rolls on a small rod passing through the centre of the rolls.

(*c*) Dry the rolls of tape in a baking oven (preferably a vacuum oven) at a temperature of 90° C. for two or three hours.

(*d*) Remove the rolls of tape from the oven and immerse them immediately while hot in a suitable insulating varnish. Allow them to remain about twelve hours in the varnish.

The specific gravity of the varnish should be maintained at about 0·85. Benzine is a suitable thinning material for some varnishes.

(*e*) Remove the rolls of tape from the varnish and suspend them in the air to dry. The tape should now be of a permanently plastic nature, and have no tendency to harden.

The coils so taped up are now ready for assembling on the armature of which the slots and end shields are insulated. This process is referred to in Chapter XI.

In Fig. 287 is given a 500-volt winding for the stator of an induction motor with a wide open slot.

For equivalent windings for lower voltages, the insulation can, from mechanical considerations, only be decreased very slightly, since, although the insulation thickness is unnecessarily great for the required disruptive strength, there is great risk of mechanical weakness with thinner insulations, and this would ultimately entail defective insulation. With this reservation, the above three examples will serve as a guide by which other types and sizes may be constructed. Great care must be taken to ensure the high quality of all the materials employed. A great deal depends upon having the varnishes adjusted to the most suitable consistency.

In the case of alternating-current machinery, still greater care should in general be given to the insulation, owing to the higher voltages generally employed, and the lower factors of safety which it is practicable to adopt. When, however, the potential does not exceed 500 volts, the insulation may be very much the same as for continuous-current machines; in fact, the present custom is to permit a much lower insulation standard than for continuous-current machines for the same rated voltage. This is a wrong tendency, and has no possible justification. In fact, for a given rated voltage, the maximum voltage occurring is higher in the alternating-current machinery to the extent that the maximum exceeds the R.M.S. voltage.

For voltages above the range of those employed for continuous-current machines, presspahn may in some cases preferably be replaced by horn fibre, owing to its higher mechanical and disruptive strength. Indeed, if manufacturing companies were not so hopelessly involved by tradition and established customs, the better material would more often be used, and with advantage, since any difference in the cost of the insulating material would be of negligible influence on the total cost of the machine. This, however, should not be taken as advocating so wastefully expensive a practice as the use of micanite linings on continuous-current motors of from 250 to 600 volts.

On alternating-current machinery of from 1000 volts upward, a moulded presspahn-mica insulation is very suitable. In such cases some firms employ micanite tubing. This is, however, not only more expensive, but, what is most important, it is more liable to be injured by moisture and dampness, which ultimately permeates the sticking varnish and causes the tube to lose its compactness and become mushy, ultimately disintegrating after long service in damp situations.

Presspahn-mica may be made up as follows:—On a sheet of oiled presspahn 0·2 mm. thick, one layer of flakes of mica is pasted slightly overlapping, over three-fourths of its surface, a rim equal to one-fourth of the width of the sheet remaining uncovered. This sheet is rolled up over a mandril and baked in a form. The mandril is of the dimensions desired for the inside of the tube. The tube may be sawn open at the top with a circular saw. The slitted tube is inserted in the armature slot, and the wires are fed in through the slit. Before pasting the flakes of mica on the presspahn, the latter should first be dried for three hours at 70° C. in a vacuum oven, and then placed for twenty-four hours in a tank of pure, double-boiled linseed oil, the oil being maintained at a temperature somewhat below its boiling-point, by means of steam-pipes lining the tank. The presspahn should then be removed and dried in an oven or in the air—the former being the quicker process, but otherwise possessing no advantage, in such a case, over drying in air.

A presspahn-mica tube 2·5 mm. thick, consisting of seven layers of presspahn and six layers of mica, should, if carefully prepared, have a disruptive strength of 30,000 R.M.S. volts. It has been found that in the construction of micanite tubes the sticking varnishes are the source of much trouble, and they should therefore be used sparingly. The adhesive qualities of the linseed oil with which the presspahn is impregnated, are sufficient, when the tube is warmed up, to be depended upon for the purpose of sticking together adjacent layers. If the ends of the tube are dipped in hot paraffin, it will prevent moisture creeping in between the leaves. Such a presspahn-mica tube constitutes a moisture and acid-proof, non-deteriorating insulation, and has the advantage over micanite tubes that the presspahn, being in one continuous piece, holds the other components firmly together. In micanite tubes, moisture penetrating into the sticker leads to disintegration. So-called micarta and pertinax tubes have recently been placed on the market by representative firms dealing in insulating materials. The pertinax tubes contain no mica.

CHAPTER XI

THE WINDING OF CONTINUOUS-CURRENT ARMATURES, AND THE DESIGN AND CONSTRUCTION OF WINDING FORMS

THE coils of continuous-current armatures are now practically always wound on formers. Form-wound coils are less universally employed in alternating-current machinery, with which we shall deal in Chapter XII.

The original Siemens drum type of armature was generally hand wound, taking the wire directly from the reel. When wound,

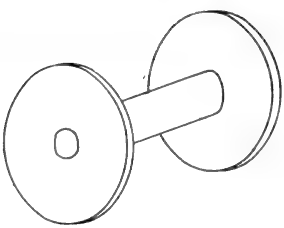


FIG. 288.—Winding Bobbin.

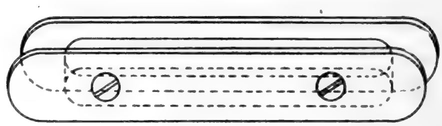


FIG. 289.—Winding Shuttle.

the ends of the coils project a considerable distance along the shaft, and are so interwoven that the repair or replacement of a coil is a troublesome matter.

The old Gramme ring type of armature construction was of the hand-wound variety, and a wooden bobbin or shuttle (Figs. 288 and 289) for holding the wire was about the only implement necessary. But with the advent of form-wound coils, a demand was created for winding forms for facilitating the winding of interchangeable coils. It has been customary for each manufacturer to devise and construct his own winding forms according to his requirements, and, as a rule, forms are being built to-day which are good for only one type and size of machine, thereby necessitating a multiplicity of winding forms which, on account of possible future repairs, must always be kept in stock ready for these emergencies.

The Alioth German Patent, D.R.P. 34,783, of 17th March 1885, is amongst the first on record showing a short, uniformly-shaped, counterpart, form-wound coil; and although there have been numberless modifications devised by others since that date which decrease the cost of winding and insulation, the mean length of turn of the coil obtained by this Alioth winding has not since been appreciably decreased by any other method.

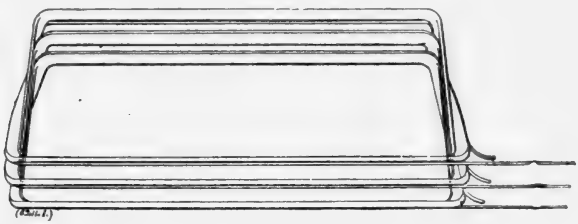


FIG. 290.—Alioth Form-wound Coils.

Figs. 290 and 291 show the coils shaped according to the Alioth method of form winding. Fig. 292 shows the arrangement of a winding form for shaping the coils.

In reference to the shortest possible length of coil, one of the authors took out a patent in 1901 (British Patent No. 17,489) for a coil shape which is illustrated in Fig. 293. This coil is based

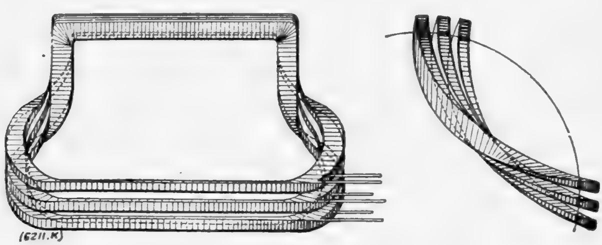


FIG. 291.—Alioth Form-wound Coils.

on the idea that the shortest coil would have its end connections formed on the principle of an equilateral triangle bent out of its original plane, and with the corners rounded off or otherwise modified to adapt it to joining the two corresponding face conductors by an essentially three-sided equilateral end connection. For a two-layer winding the coil would be conveniently formed to the shape shown at the top of Fig. 293, and afterwards spread to the shape shown in place on the armature in the lower views.

The Eickmeyer coil (English Patent 2246, 6th April 1888) was one of the earliest form-wound coils to be adopted in America. Its distinguishing characteristics comprised a bottom slot portion shorter than the upper slot portion, thus allowing the end connections to be looped downwards towards the shaft, and shortening up the total armature length, which in a tramway motor is an important consideration.

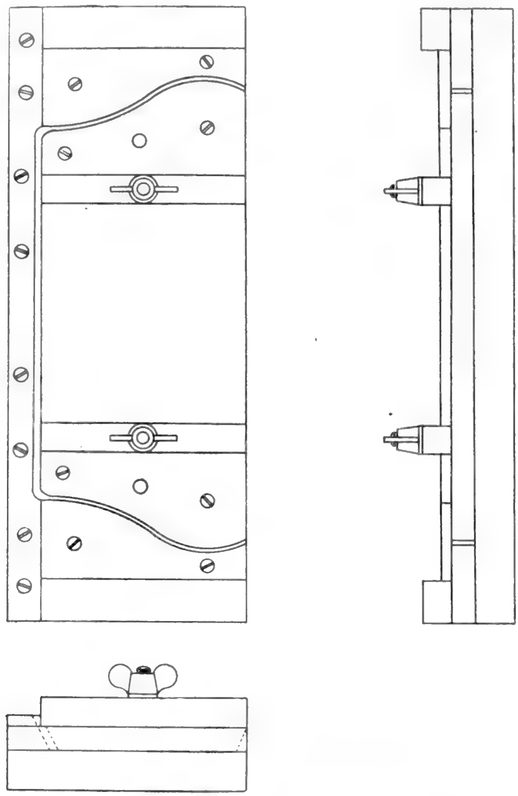


Fig. 292.—Former for Alioth Coils.

Fig. 294 shows the shape of coil for the Eickmeyer winding. The end portions of the coils are really laid up in two separate more or less vertical planes situated one behind the other when the winding is completed. It is this feature which renders the distance to which they project somewhat shorter than in the case of a barrel winding, where the end portions lie up in two concentric cylindrical planes—the ends projecting in the plane of the armature surface, and not being bent down radially.

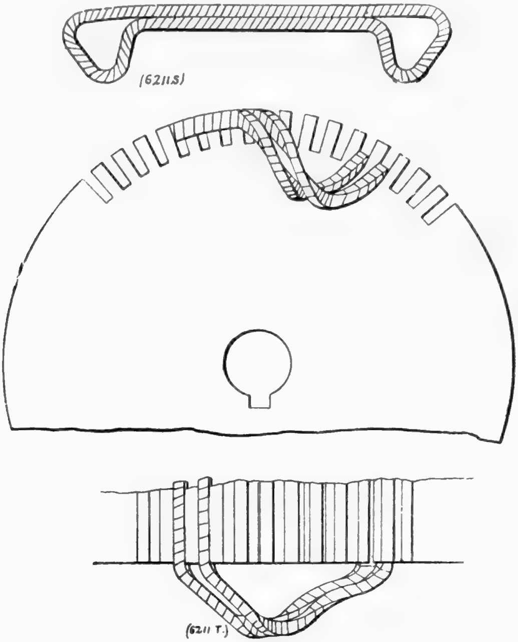


FIG. 293.—Hobart's Form-wound Coil.

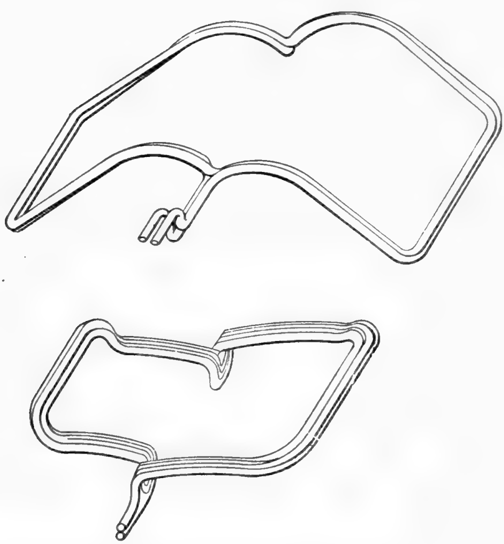


FIG. 294.—Eickmeyer Form-wound Coil.

The Webber winding form (U.S. Patent 561,636, of 1896) facilitated the construction of coils of the Eickmeyer type. Fig. 295 shows the shape of the Webber coil. Fig. 296 shows the

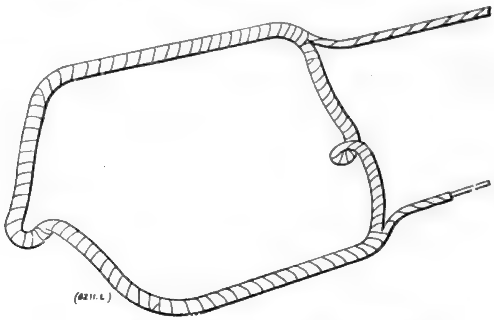


Fig. 295.—Webber Form-wound Coil.

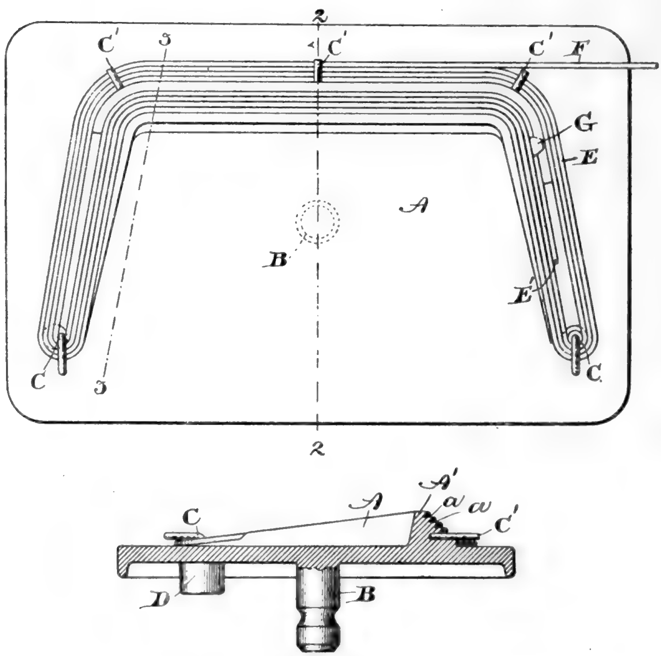


Fig. 296.—Form for Webber Coil.

method of winding and the winding form, which consists of a baseboard from which project pegs at appropriate points, and the coil is wound by carrying the wires around the path defined by these pegs.

For quick repairs a form could be improvised with four round nails or pins driven into a board, together with two corner-pieces shaped step fashion out of fibre or metal, as in Fig. 296. The coil when wound is of the shape shown in Fig. 297, and after leaving the form it has to be "spread." This may be done by means of a form constructed on the general principles illustrated in Fig. 297. This form may consist of a board with two cavities into which the

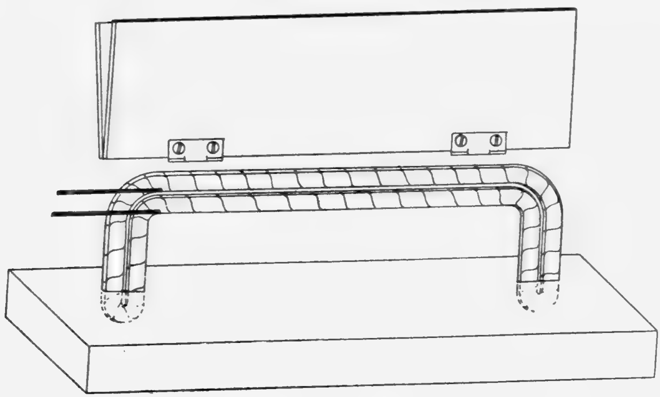


FIG. 297.—Simple "Spreading" Apparatus for Armature Coils.

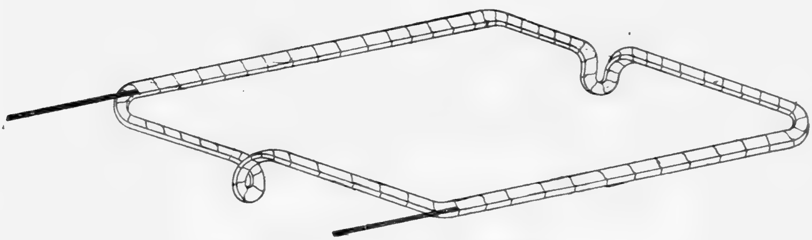


FIG. 298.—Coil after Spreading.

bottom loops of the coil are inserted, and then by means of a hinged spreader the top and bottom portions of the coil are swung apart. The coils thus formed are of the general shape indicated in Fig. 298, and in this shape the coils are then taped, after which the coils are pressed into their final shape by means of a third form. This is shown in Fig. 299, and consists of two blocks between which the coil is pressed.

The desire to avoid the payment of royalties under the Eickmeyer patents served as an incentive toward the perfection of other form-

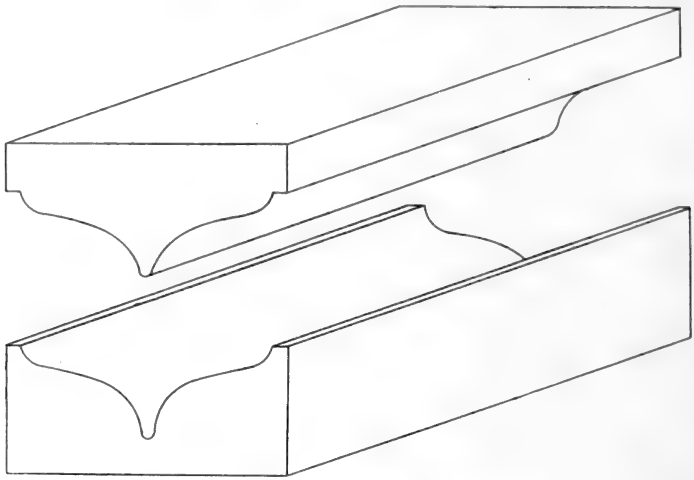


Fig. 299.—Block for Pressing Armature Coils.

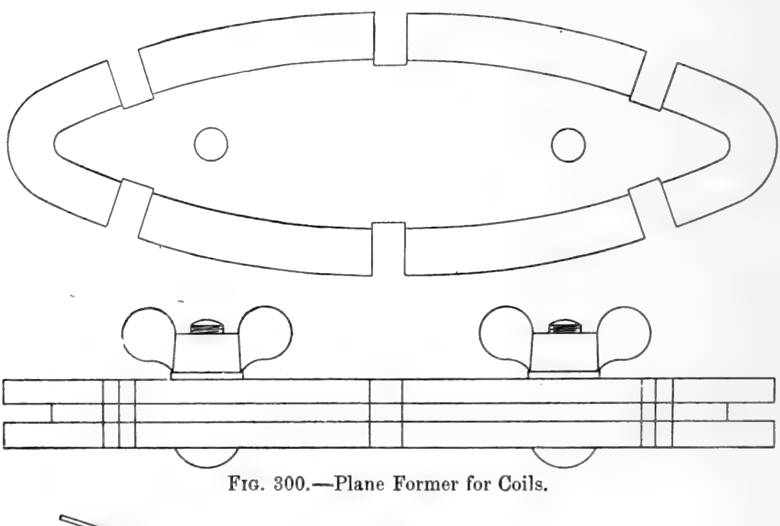


Fig. 300.—Plane Former for Coils.

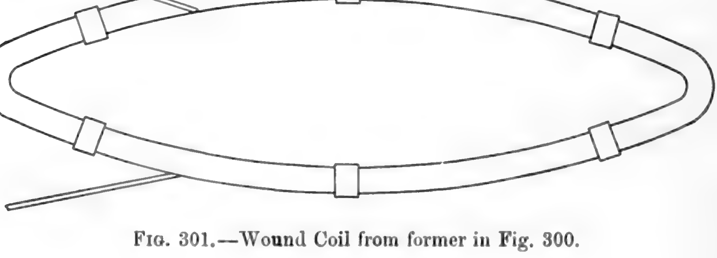


Fig. 301.—Wound Coil from former in Fig. 300.

wound coils, such as the barrel type or diamond-shaped coils. With coils of these types, supporting end flanges were added to the armature core construction.

These coils could be wound in a simple form of some such type as that indicated in Fig. 300. The central elongated-formed block of wood in Fig. 300 is provided with holes for the reception of two bolts with wing nuts which clamp the central block between two side blocks. The central block and side blocks

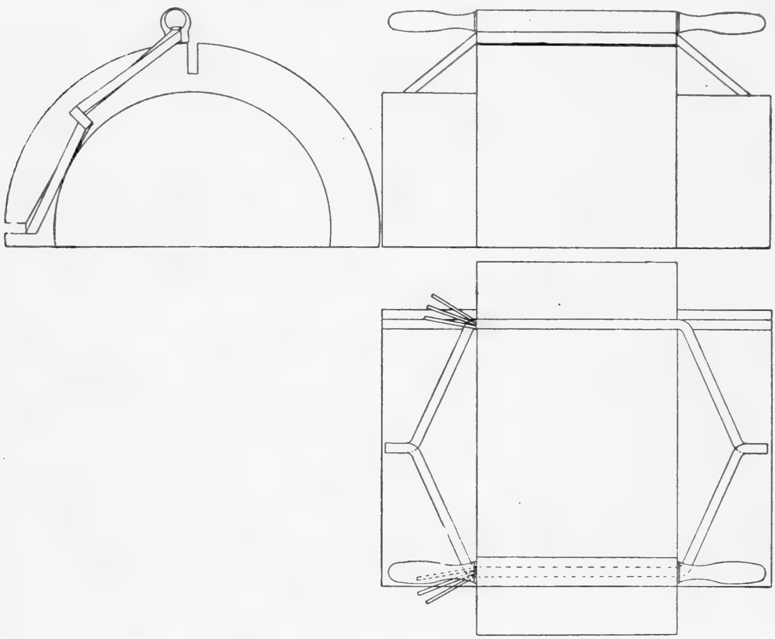


FIG. 302.—Simple Hand-spreading Apparatus.

are so recessed as to provide spaces for a number of lead or soft iron strips which are laid in place prior to winding the coil. After winding the coil the lead strips are bent up over the coil, which thus remains held in shape after removing it from the form. At this stage the coil presents the appearance indicated in Fig. 301.

Fig. 302 illustrates a simple way by which it may be next spread out to a so-called diamond-shaped coil. The apparatus consists simply of a wooden dummy of the same diameter as the armature, and having one slot into which one side of the coil is placed; the other side is taken into the groove in a piece of wood, with handles at each end, which is pulled round on the surface of the dummy until the coil is the correct width and has the final form indicated in Fig. 302.

A combined winding form and spreader, designed by H. W. Turner, is shown in Fig. 303. By means of this apparatus three coils can be simultaneously wound, the apparatus being attached to a winding lathe face-plate. The process of winding with this apparatus is illustrated in detail in the photographs of Figs. 333 to 339.

A universal spreader which is adjustable for any size of diamond-shaped coil, is shown diagrammatically in Fig. 304.

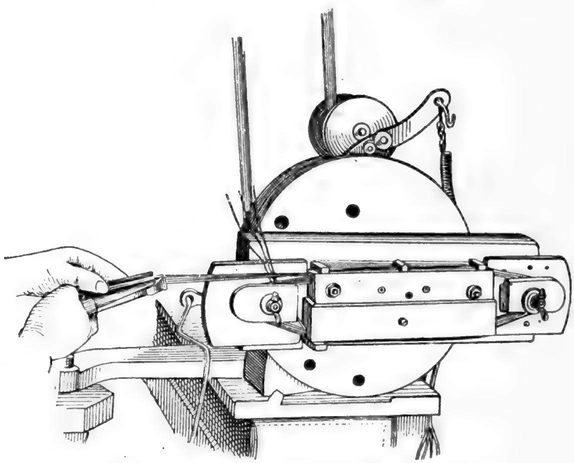


FIG. 303.—Turner's Combined Winder and Spreader.

The sides, *i.e.* the slot portions of the coils, are held in the clamps *b* and *c* attached to the bars *e* and *g*. These clamps are capable of adjustment longitudinally to suit coils of different length. The corners of the coil are secured to clamps *n n*, which are capable of sliding on a straight bar *o*. One side of the coil is thus held on the fixed part of the apparatus *d*, and the other on a movable arm *h*.

The coil after winding is put into the clamps *b*, *c*, and *n*, the bars *e* and *g* being close together. To spread the coil the arm *h* is moved outward about the pivot *l* by pulling the handle piece *k*. The clamps *n n* slide towards one another, and the end parts of the coils *a* are drawn inwards, until the coil has attained the required breadth. This machine may be adjusted to suit any size of coil smaller than the largest coil which can be carried by altering the position of the clamps *b* and *g*.

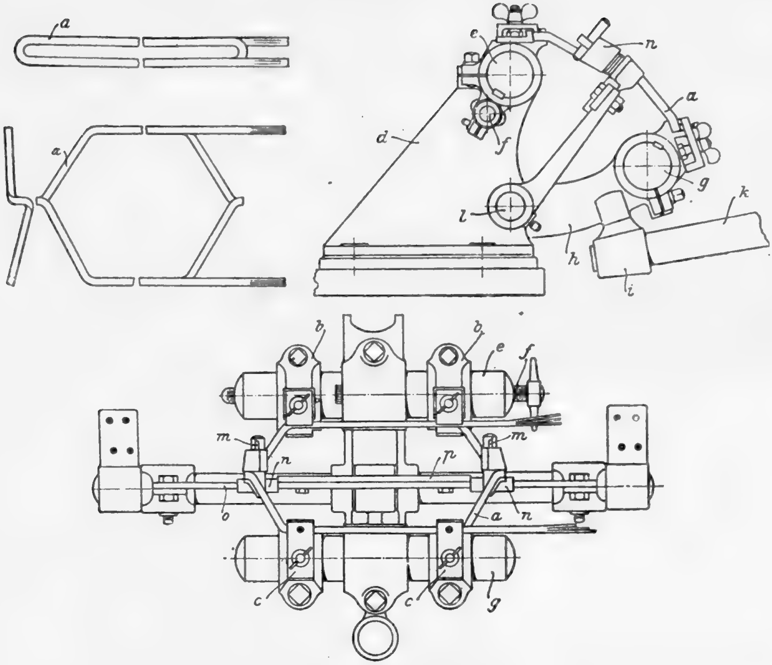


Fig. 304.—Universal Spreader.

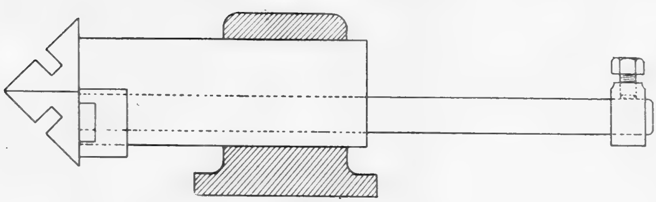


Fig. 305.

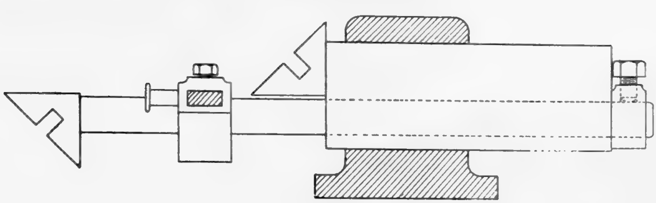


Fig. 306.

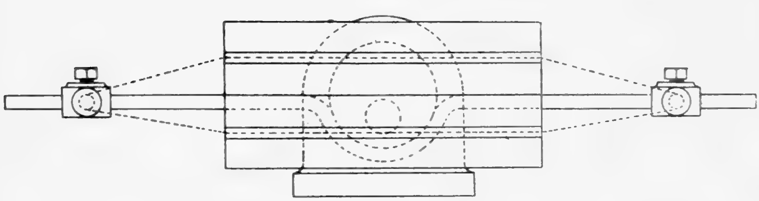


Fig. 307.

Hanson's Combined Winder and Spreader.

By far the most ingenious combined winding form and spreader is that invented in 1898 by A. P. Hanson for the Union Elektricitäts Gesellschaft of Berlin, Germany. This machine not only winds and spreads, but is also adjustable to many sizes of coils, making it very useful for small factories where the outlay for tools must be kept low. Figs. 305, 306, and 307 illustrate the

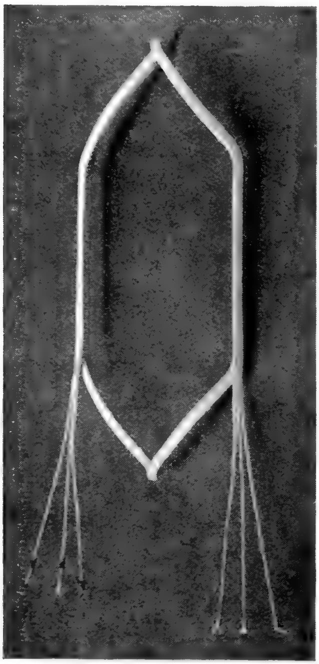


FIG. 308.—Three-turn Wire-wound Armature Coil.

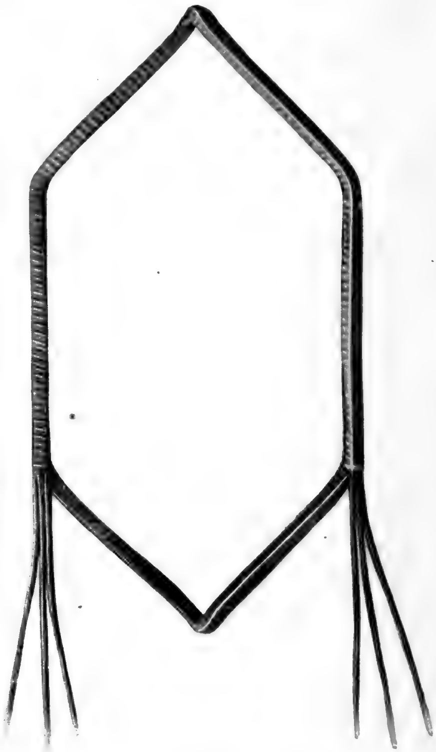


FIG. 309.—Three-turn Wire-wound Armature Coils.

principle of this machine. Figs. 305 and 307 show the position of the parts during the winding of the coil, the outline of which latter is shown dotted in Fig. 307. When the coil is wound, it is spread by sliding the piece holding one side, into the position shown in Fig. 306, the ends of the coils drawing in towards one another during the operation, along the axis shown in the plan of Fig. 307.

Figs. 308 and 309 show typical, finished, wire-wound coils. Each of these coils is a composite coil consisting of three component coils per slot, as indicated by the three ends projecting from each of the slot portions of the coil, and for this reason it may be designated a "triple coil."

We have now dealt with the chief methods of constructing forms and coils for continuous-current armatures, and the underlying principles of these govern the construction of the various other forms and other methods, some of which we shall consider subsequently.

Strip-wound Armature Coils.

Most of the previous methods and forms have applied to wire-wound coils. We shall now deal generally with strip-wound coils, and later give a typical example of a case with this type of winding.

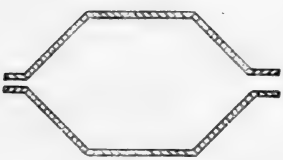


Fig. 310.—Jointed Strip Coil.

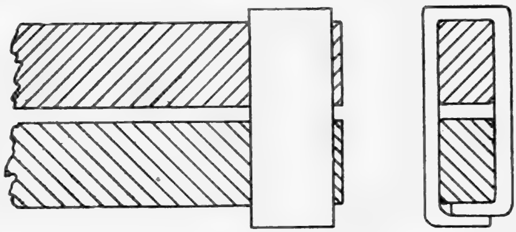


Fig. 311.—Strip Coil Joint.

In laying out the windings for a strip-wound barrel type of armature, one of the first questions to be decided is whether we will have soldered or jointless connection between the top and bottom halves of the windings. The arguments in favour of soldered connections are that as the defects to which armatures are most liable are those which occur near the surface, sometimes by being damaged in transport, and more frequently by moisture condensation on the surface, such defects are easily remedied by unsoldering the joint at the back loop, and raising the top half of the winding, repairing same, and replacing the bar, the two halves of the coil being as shown in Fig. 310. In high-speed machines, such as turbo-generators and motors, it is quite essential that we have a joint at the back end as indicated in Fig. 311, on account of the better mechanical means of binding the bars in place. The bottom layer of the windings is first put in place, and bands are put over these to hold them fast before the top half of the winding is put in, and then the back loops are soldered. But with moderate-speed machines this is entirely unnecessary; a jointless winding is much more cheaply and easily wound, insulated, and assembled, and if the jointless method is decided upon, the question arises whether we shall adopt a radial half-turn loop (Fig. 312), an oblique half-turn (Fig. 313), or a cross between these two (Fig. 314). The radial half-turn loop requires that the copper should be bent over a very small radius, as Fig. 312: thus thickening up the copper at

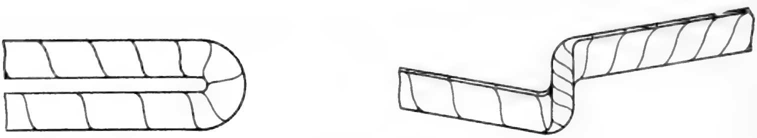


FIG. 312.—Radial Half-turn Loop.

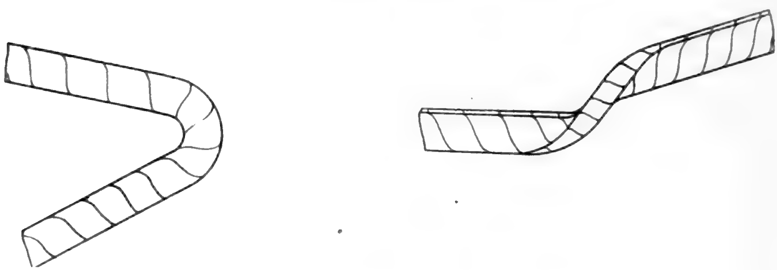


FIG. 313.—Oblique Loop.

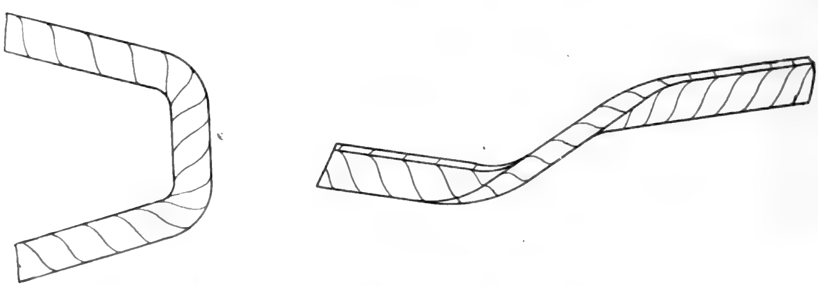


FIG. 314.—Composite Loop.

this point, and adding difficulties to the insulating methods; and the copper is apt to be weakened mechanically. The oblique half-turn loop, on the other hand, possesses the advantage of being more easily bent over a much larger radius, as Fig. 313, without danger of cracking the copper during the bending process; further, it reduces the weight, therefore the length, of copper required, affords better ventilation for the windings, and facilitates the insulating process. But, still better, the cross between the radial half-turn and the oblique half-turn (Fig. 314) gives greater space between the top and bottom bars, and in some cases will not require supporting flanges underneath the overhanging windings at the ends. In all three methods the copper is first cut in lengths, and, if there is more than one bar in a slot, these bars are all bent together at one operation, the back end loop being bent first. Then the copper is annealed at this point, and the bars are shaped on the former, after which the bars are marked in consecutive order so that when these bars are insulated they may be re-assembled in bundles corresponding to the way in which they were bent.

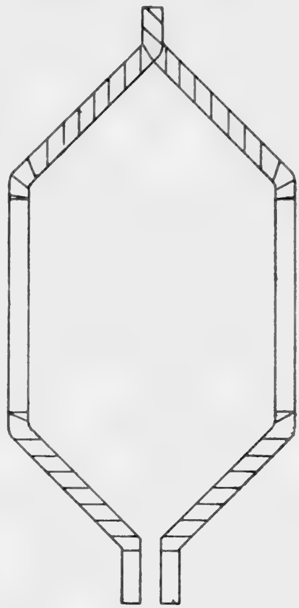


Fig. 315.—Coil with End Parts only Taped up.

The bars may then be washed in a bath of benzine, and dipped in an insulating varnish thinned down to about 0·83 specific gravity. These bars are then placed in a baking oven and well baked. The object of this coating of varnish is to protect the copper from verdigris, as well as to give it a good insulating film. Naturally the copper edges must be well rounded, in order to obtain the best results, before they are coated with the varnish. The bars are then ready to be insulated.

Frequently the practice is adopted of taping the ends, leaving the slot portion bare, as in Fig. 315. The slot portion may then be insulated by a strip of mica cloth or mica paper, cut as wide as the slot portion is long, and interwoven so that one layer of this insulating material separates the bars, as in Fig. 316.[1] The surplus end of the insulation is then wrapped around the assembled bars, making two or more layers, according to the voltage of the machine and insulating space available in the armature slot. A layer of tape is then put on top of this insulation, and the completed bars are dipped

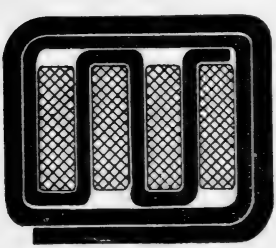


Fig. 316.—Insulation of Group of Bare Conductors.

[1] The thickness of the vertical insulation between the conductors is exaggerated in Fig. 316.

in an insulating varnish and oven-dried. The bars are now ready to be placed in the armature slots.

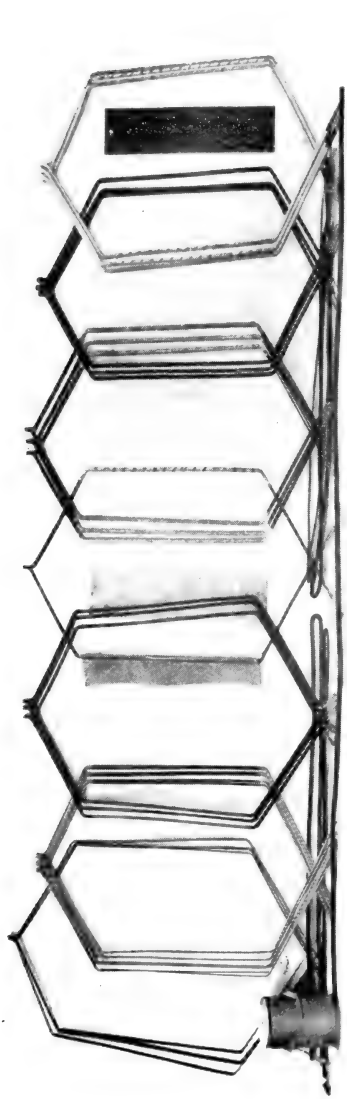


FIG. 317.—Evolution of a Strip Coil (Dick Kerr & Co.).

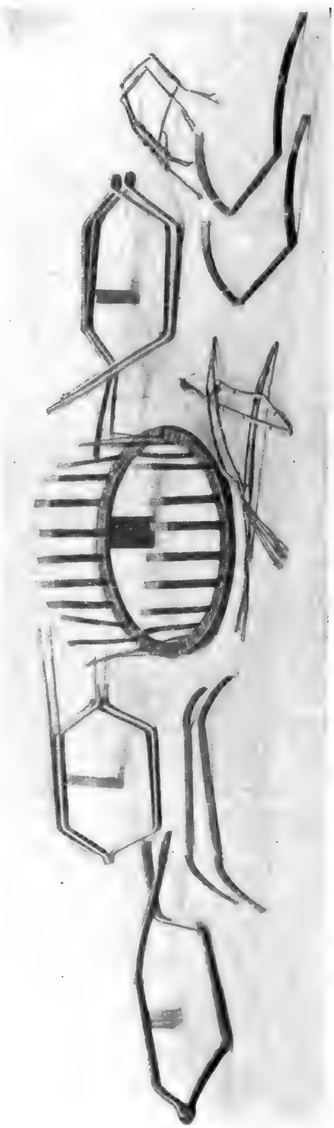


FIG. 318.—Typical Armature Coils (Vickers, Sons & Maxim).

Fig. 317 illustrates the process of evolution in the construction and insulating of a strip-wound coil. The extreme left-hand coil shows the copper strip immediately after leaving the former.

The second coil has its end parts taped up as has been indicated in Fig. 315, and in the third view the end portions have been varnished. The fourth view shows a single turn with the insulation being applied to the slot portions of the conductors. The right-hand side of the turn is taped up over the layer of insulation. The fifth coil shows the double taping on the slot portions of the conductors, and in the sixth coil the whole is

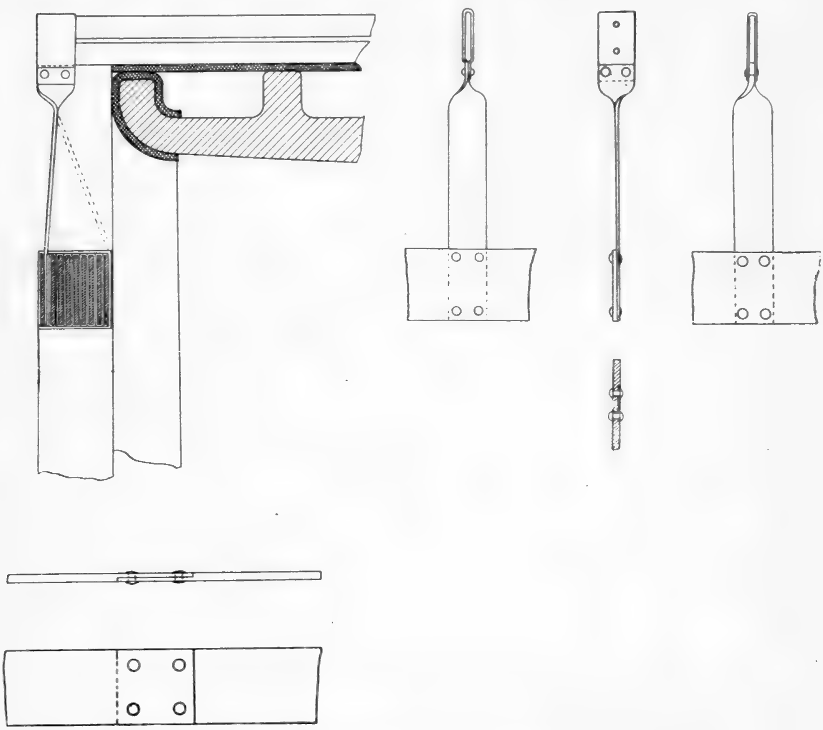


FIG. 319.—Equaliser Ring Construction devised by Hobart in 1901.

shown varnished. The coil is now, after being oven-dried, ready for assembling in place on the armature.

Fig. 318 shows a miscellaneous group of strip- and wire-wound coils. There are three complete lap-coils with radial loops at the ends. On the extreme right is a smaller coil with an oblique loop of the type described on p. 266.

In the front are to be seen several half-turns for lap-windings having joints at both back and front ends; the piece in the centre is a finished set of equaliser rings and tappings to the armature windings. This method of binding up the equaliser rings into a solid group yields a compact job, and the arrangement will be more clear from the sectional sketch in Fig. 319, which was prepared in 1901 according to the directions of H. M. Hobart, to whom the arrangement is due.

Fig. 320 shows a large armature, designed by one of the authors in 1901, with the equalisers done up in this way. The method

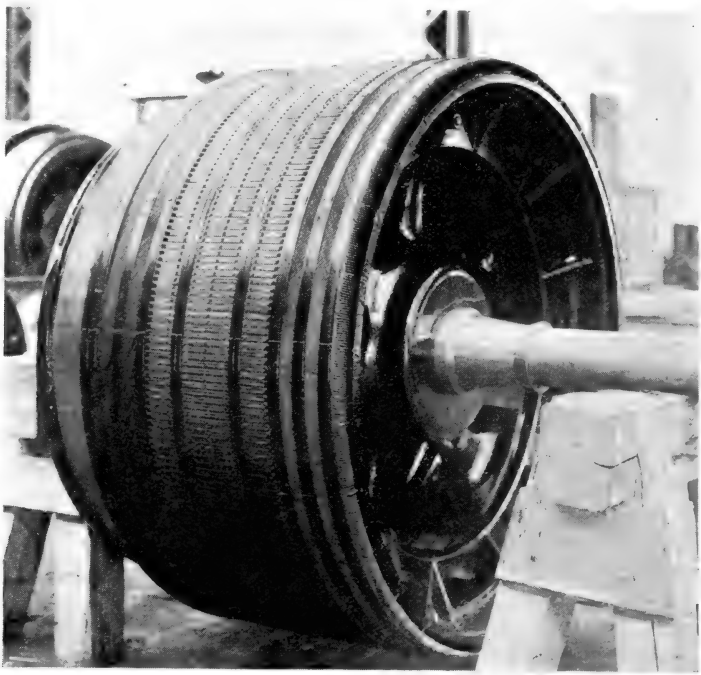


FIG. 320.—Large Armature, showing Equaliser Ring Construction (Union Electric Co. of Berlin).

employed by the General Electric Company (U.S.A.) is illustrated in Fig. 321. In this method the rings are spaced from each other and from the armature body by grooved wooden blocks placed at intervals around the armature.

It has occurred to the writers that the most useful way to deal further with the matter will be to describe the forms and accessory tools which should be provided for dealing in an up-to-date manner with the requirements of certain concrete cases.

Let us begin with the case of a strip-wound, 6-pole, 250 k.w., 320 r.p.m., 550-volt railway generator, whose slot cross-

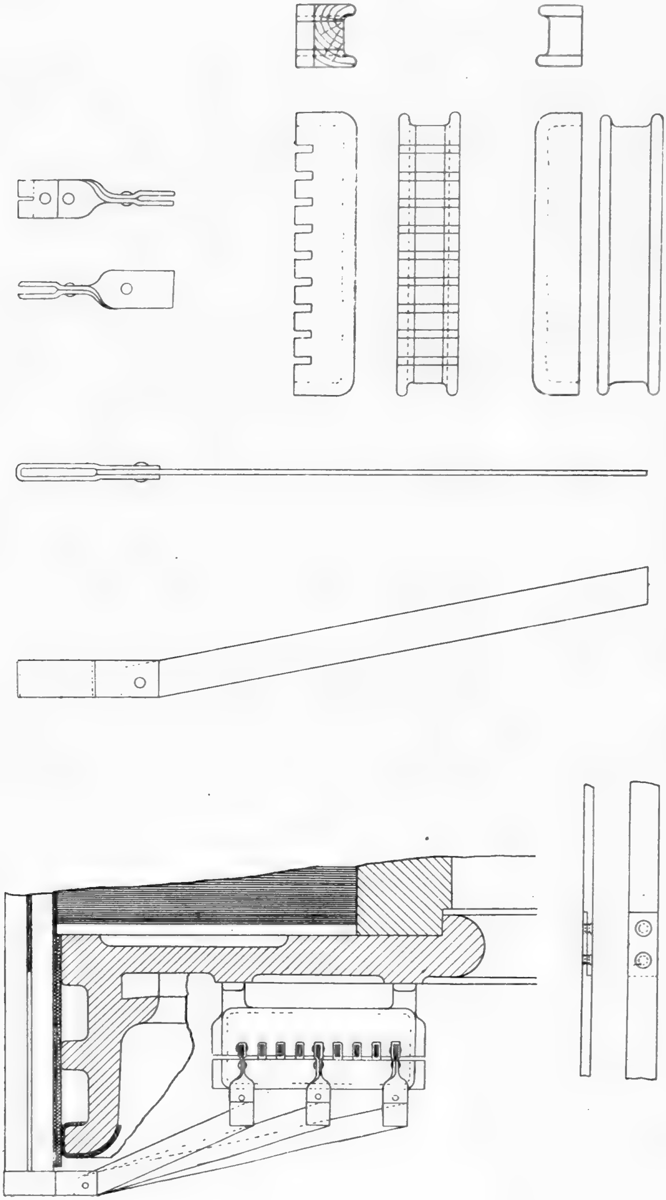


FIG. 321.—General Electric Co. (U.S.A.) Construction for Equaliser Rings.

section is shown in Fig. 322. There are eight conductors per slot, and each conductor measures 12·0 mm. × 2·5 mm. A developed plan of a portion of the winding is given in Fig. 323. The first question to be decided is whether we shall have a joint at the back end, or whether we shall have a continuous strip for the complete turn, thus having only joints at the front end. The arguments in favour of joints at both ends are based on the fact that windings are more frequently found defective on those parts nearest the surface; moisture condensation and transportation difficulties are sometimes responsible for this. Then, again, if the windings are in halves, the bottom layers may be securely fastened down on to

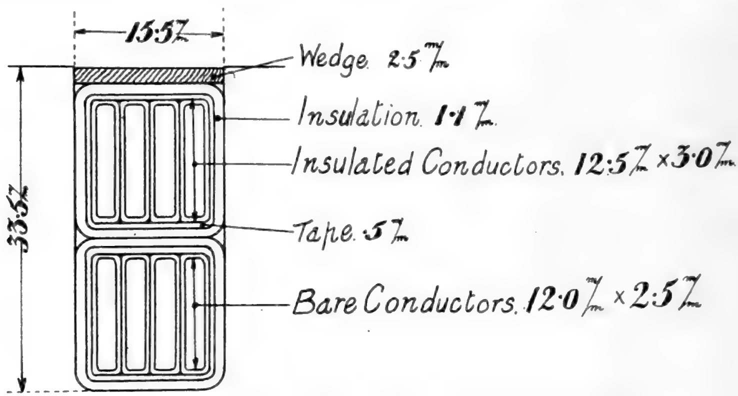


FIG. 322.—Section of Slot of 250 k.w. 550-volt Generator.

the end-supporting flanges before the upper portions of the coils are put in place. This argument is perfectly sound in the case of turbo-generator armatures, and in high-speed machines in general.

The arguments in favour of jointless windings are based on the saving in time and money, and the avoidance of possible poor soldering in the joints and of scattered drops of solder in the windings. Jointless windings may save as much as 20 per cent. in time of making and assembling coils on the armature, and the absence of joints gives a greater security from breakdown.

This latter is the preferable plan in the present instance. By scaling off from the drawing, we find that the total length of one turn from beginning to end is 230 cms. The armature has altogether 600 turns; hence we must first cut up 600 strips of copper with a length of 230 cms., and measuring in section 12·0 mm. × 2·5 mm. The weight of copper required may be calculated from the section of the conductor and length of the turn. The cross-section is $1·2 \times 0·25 = 0·3$ sq. cms., and the mean length of one turn is 230 cms. The weight of a cubic centimeter of copper

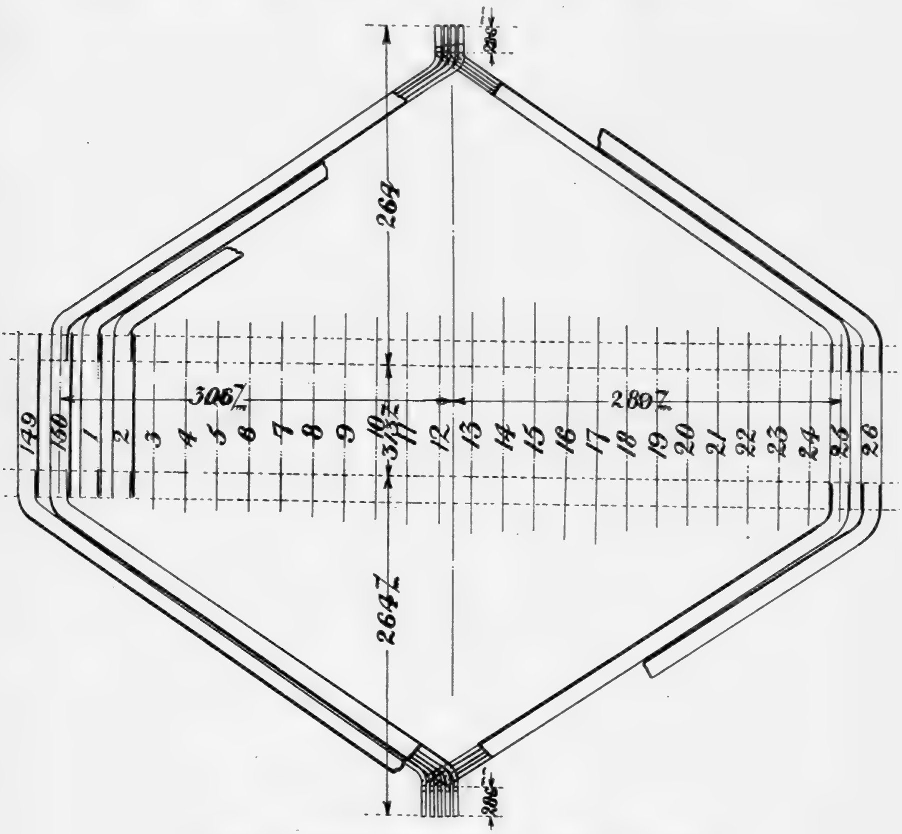


FIG. 323. Developed View of Winding of 250 k.w. Generator.

is 8·9 grams, and hence the weight of one turn is $\frac{230 \times 0·3 \times 8·9}{1000} =$ 0·615 kgs. As there are 600 turns the total weight of strip copper required is $630 \times 0·615 = 387$ kgs., or about 0·4 ton. The copper constituting this strip must be specified to have its edges well rounded. The principle of the machine by means of which the bend at the back end is effected, is that of the tool shown in Fig. 324.

A large machine actually employed for such work is shown in Fig. 325. After bending, the strip has the form indicated in Fig. 326. A bundle of four such strips (consisting of the four conductors which go to make up the half contents of a slot) are next placed on a form of the type shown in Fig. 327, and by the means there indicated are bent into the required shape.

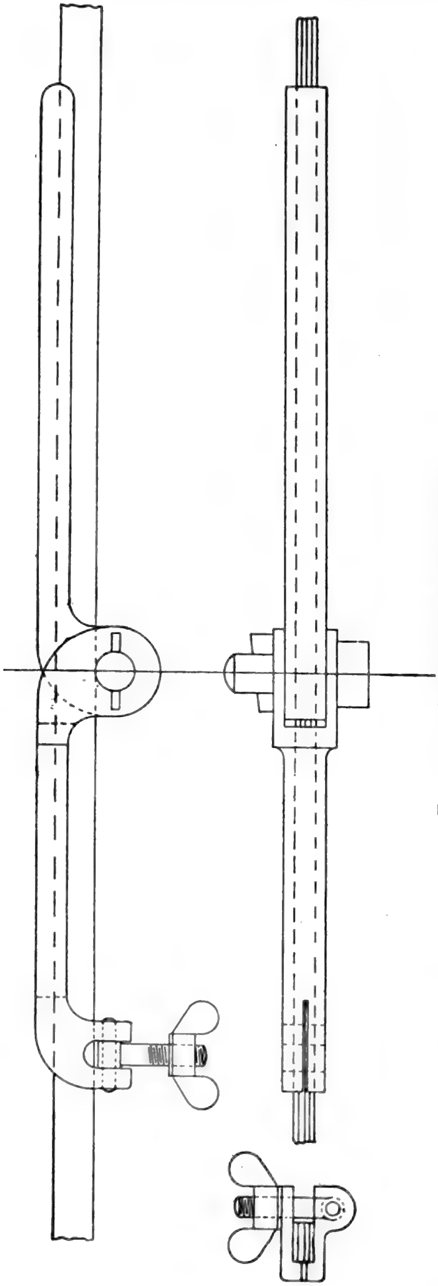


FIG. 324.—Strip-bending Hand-tool.

This form consists of a base with its upper surface curved to the radius of the armature at the bottom of the slots. From the surface project ribs (shown screwed on) which form a contour of the shape which the coil is required to have. The two sides of the strip are first opened apart at an angle and placed on the form at the front end, and secured by the screw shown in the lower view.

Commencing now with the right-hand side of the strip, it is bent to shape on the surface of the form following the contour of the projecting ribs, and securely clamped on to them from point to point by the clamps marked A.

These clamps are of

an ingenious nature, enabling the strip to be clamped quickly; an end view of the clamp is shown in the centre of the upper view. The hand-piece is fixed to a spindle, the body of which is eccentric

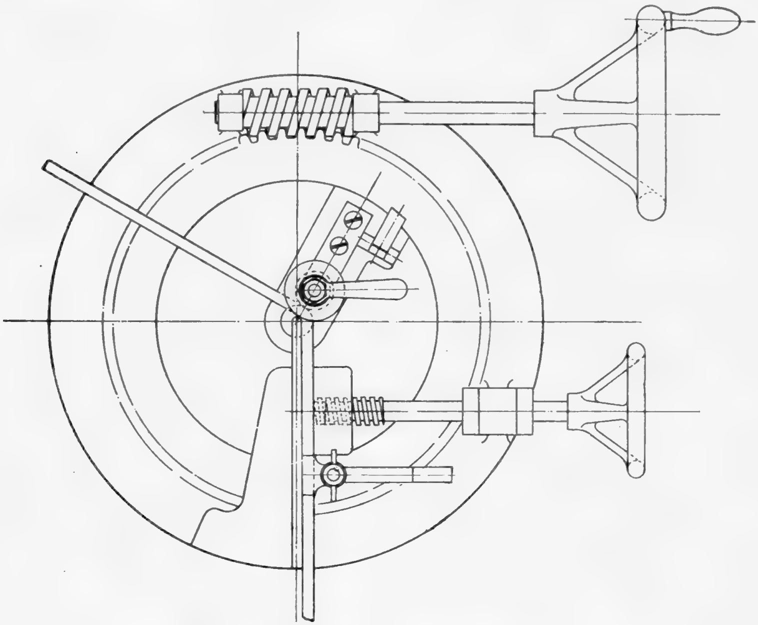


FIG. 325.—Large Strip-bending Machine.

to the bearing parts, so that when the handle is pressed down by hand in the position shown in the view at the centre of Fig. 327, the clamping piece is drawn back a little and just grips the strip clamping it to the side of the ribs.

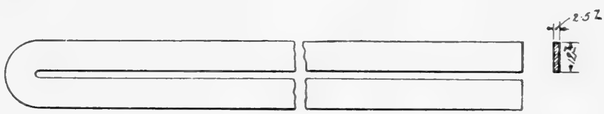


FIG. 326.—Strip after Bending.

When the one side of the strip has been bent round the form, the end is brought out straight by bending it round a pin, which is inserted in a hole in the form.

The other side of the coil is shaped in an exactly similar way, the pin being used for both sides, and chained to the form to prevent it getting lost.

The coils so shaped are taped in the manner outlined already

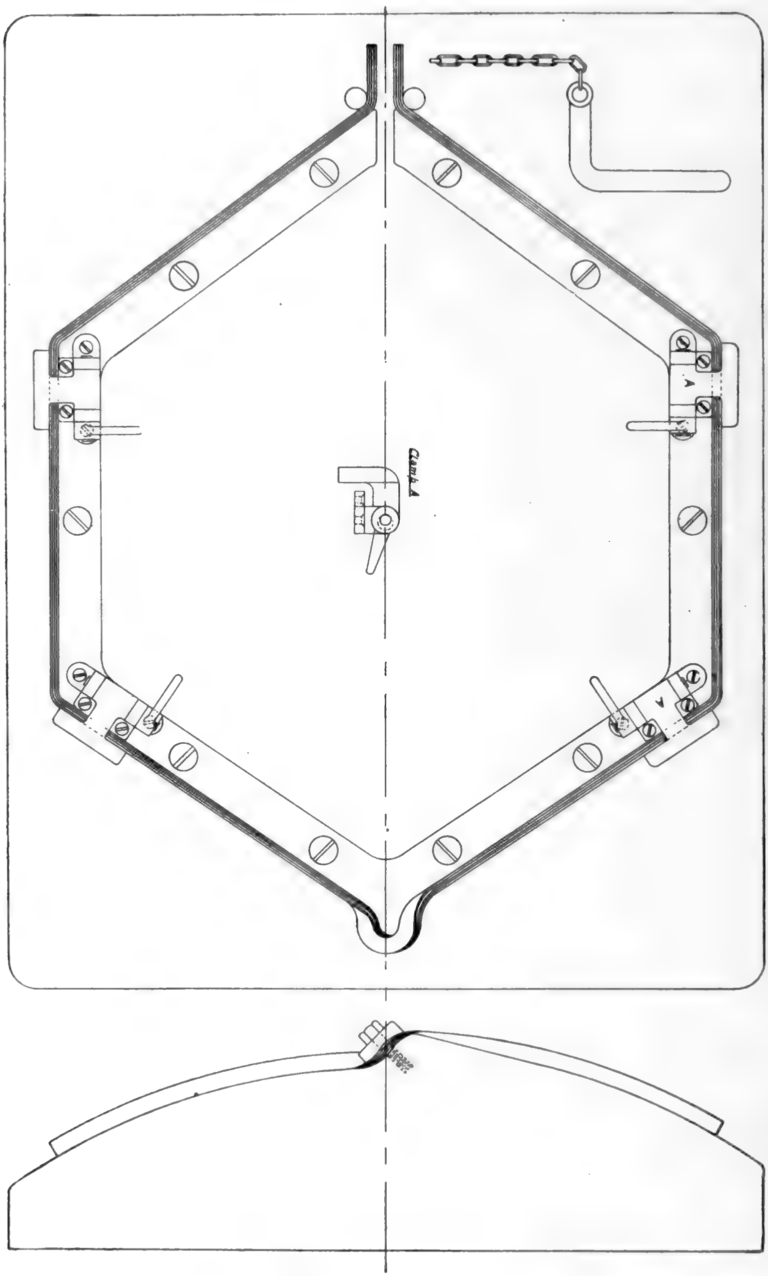


Fig. 327.—Form for Strip Coils.

in this chapter, and on p. 251 of Chapter X. Two typical taping machines are illustrated in Figs. 328 and 329.[1]

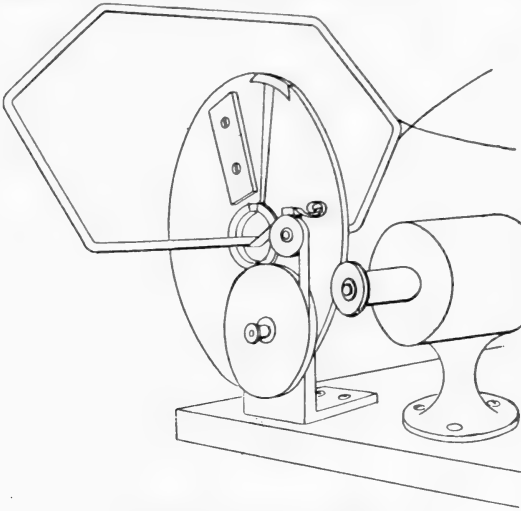


FIG. 328.—Coil Taping Machine.

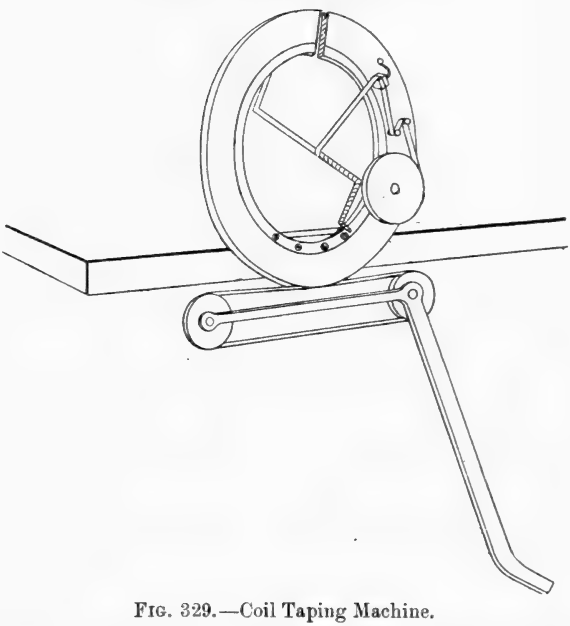


FIG. 329.—Coil Taping Machine.

[1] A number of alternative designs for taping machines are described in Chap. xix. of *The Insulation of Electric Machines*, Turner and Hobart (Whittaker & Co., 1905).

Before applying this tape, it must be dried in a vacuum oven for a number of hours, and must not be taken from the oven until immediately prior to use. The taped conductors are next thoroughly dried in a vacuum oven,[1] and are afterwards subjected to one or more dippings in some suitable impregnating varnish,[2] each dipping being followed by vacuum oven-drying.

The conductors are again made up into groups of four, and are covered first with wrappings of empire cloth and afterwards with another serving of cambric tape, wound on with the machine already shown in Fig. 328 or Fig. 329. This outer serving of tape is mainly for the purpose of giving stability to the completed coil,

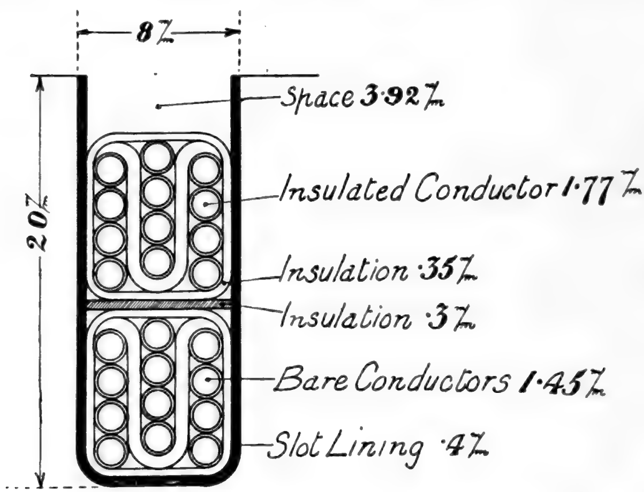


Fig. 330.—Section of Slot of 10 h.p. 500-volt Motor.

which is again subjected to the dipping and drying process, and is then sent to the stores pending its being requisitioned for assembling on the armature.

Let us next consider the case of a 4-pole 10-h.p. motor for 500 volts and 950 r.p.m. A cross-section through the slot of this machine is given in Fig. 330.[3] End and plan views of the winding are given in Fig. 331. The windings as arranged in place on the

[1] A number of types of vacuum ovens are described in Chap. xx. of *The Insulation of Electric Machines.*

[2] The subject of insulating varnishes is fully discussed in Chap. viii. of *The Insulation of Electric Machines.*

[3] The thickness of the vertical insulation between the coils of wire is exaggerated in Fig. 330.

armature core will be understood from the section through the armature core, shown in Fig. 332. A standard motor of this rating will be made in large quantities, and the first cost of the

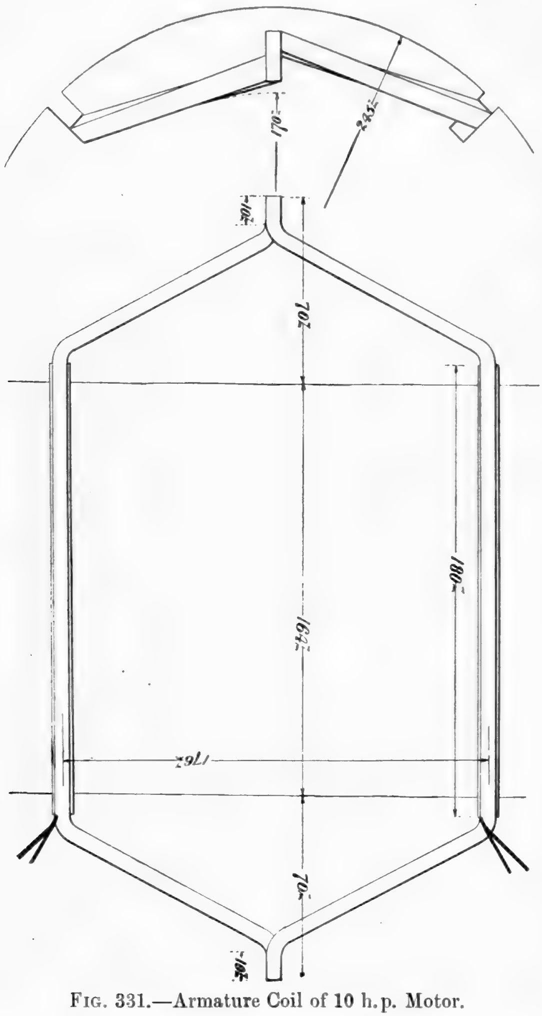


Fig. 331.—Armature Coil of 10 h.p. Motor.

manufacturing appliances is of less consequence, provided this leads to a decreased labour cost and a thoroughly satisfactory result as regards quality of the product.

There are several ways of constructing a winding form for this case. The first method we shall describe shows in detail at the various stages the process which has already been referred to on p. 262 and Fig. 303.

Triple-coil Winding Forms.

I. The windings in the present case, as in many classes of tramway armature, consist of three separate coils, which in most cases are wound singly, and afterwards assembled together during the insulating process. These coils, being all wound on the same form, require a fair amount of skill and care in assembling the component parts so that they fit well together. In order to avoid these difficulties, and to cheapen the labour

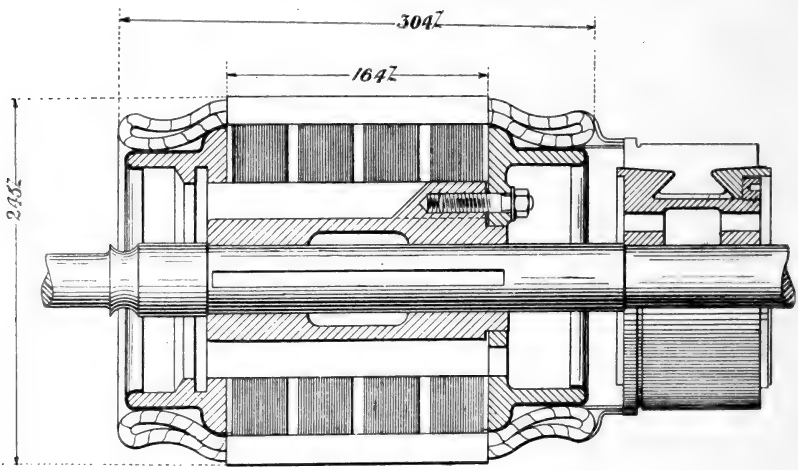


Fig. 332.—Section through Armature of 10 h.p. Motor.

costs, it is desirable to wind these three coils simultaneously, and Figs. 333 to 339 illustrate a practical way devised by H. W. Turner in 1897.

Fig. 333 shows the winding form attached to the head of the winding lathe, with the three wires attached ready for winding. The reel of wire is seen on the left, and the method of tensioning is shown—the wire being clamped between two blocks, and the tension adjusted by the tightness of the clamping bolts.

Fig. 334 shows the form in a position after the first turn has been made, and the method of applying the V-shaped coil separator in the slot portion of the coil. This will be seen as the strip of insulation embracing the middle wire of the three, and thus insulating the middle layer from the outers.

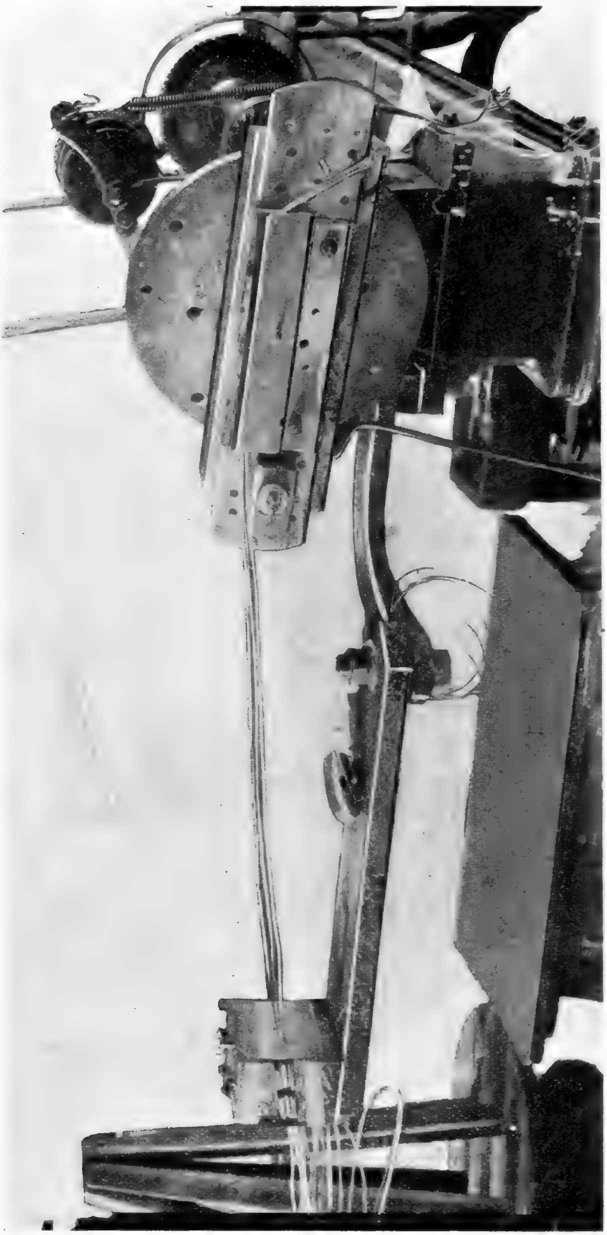


Fig. 333.—Winding Triple Coil—Commencement.

Fig. 335 shows the method of making the wire lie fast and straight in the slot, by means of a wooden wedge, after which the wood buttons are turned over to retain the wires firmly in place during the subsequent operations.

Fig. 336 shows the wires being cut to the required length after the coils are wound complete on the form.

Fig. 337 shows the first forming operation ; the pieces which held the ends of the coils are removed, and the ends are being given a quarter twist by hand.

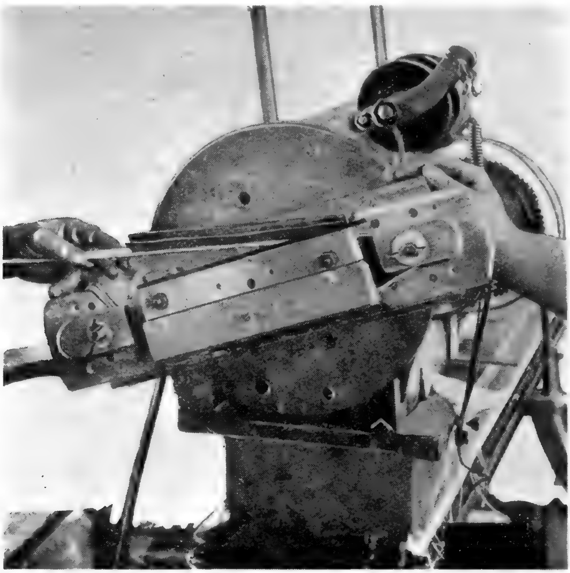


Fig. 334.—First Turn and Insertion of Insulation.

Fig. 338 shows the coil being spread, that is, stretched out to the right width to cover the correct pitch of the armature slots. It will be noted that the end twists are still held during this operation to prevent them from being deformed.

Fig. 339 shows the finished coil being removed from the form. Lead or soft iron clips are put on the coil at intervals to retain its shape until the taping process, during which they are removed.

II. A second way is to wind the coil over two pins in the manner shown in Fig. 340. After the coil is wound, and the wires held fast together with metal clips (thin strips of lead, tin, or iron), the coil is dried in an oven, and then dipped while hot in an insulating varnish and oven-baked until dry.

The slot portion of the coil is then insulated one section from another by interlooping a strip of treated linen, as is shown in the cross-section of the slot in Fig. 330. This strip is cut so long that it may be wound around the complete bundle at least $2\frac{1}{4}$ times. The parts of the coils outside of the slot portion are now covered by one layer of tape. The coil is now ready to be spread to its proper shape, and for this purpose a dummy wooden model of the armature core is employed of the type already shown in Fig. 302,

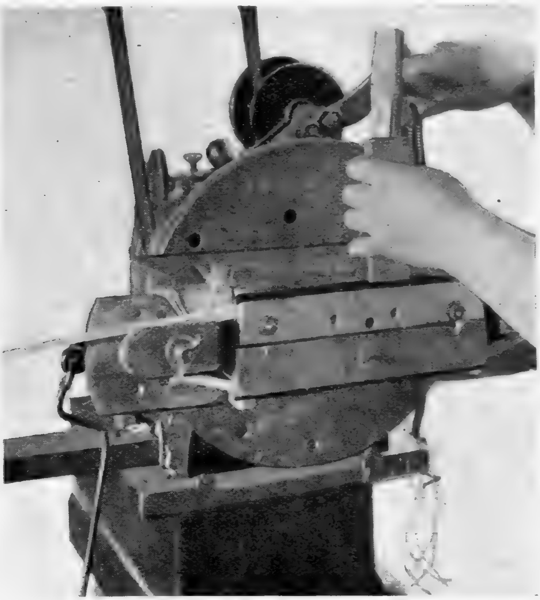


Fig. 335.—Wedging Coil in Slot

having one slot into which the bottom half of the coil is inserted. The coil is then spread by placing a slotted wooden piece over upper portion of coil, and sliding this piece with its part of the coil over the core periphery until the desired shape is attained and the coil has the correct pitch.

The coils are now ready to be placed in the armature core slots directly after the treated presspahn, fuller-board, or other similar materials used for slot linings, are in position. The completed armature should be placed in a baking oven and thoroughly dried, after which it should be plunged while hot into a bath of insulating varnish and afterwards oven-dried.

III. A third way of winding these coils is to wind each com-

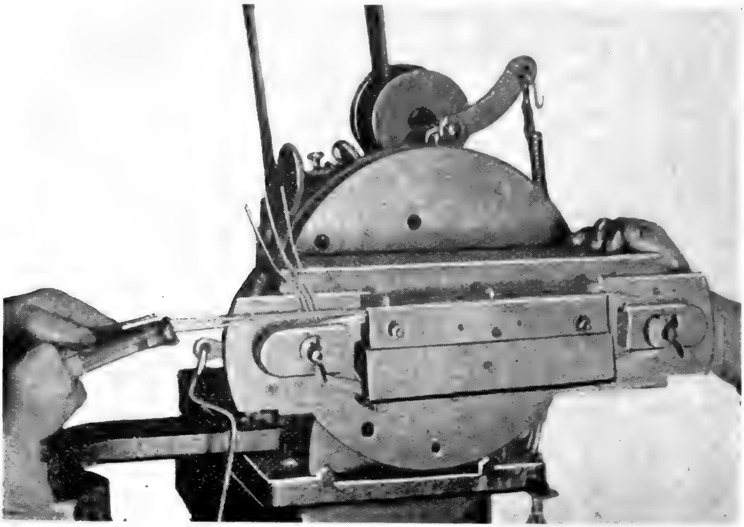


FIG. 336.—Cutting off Wire after Completing Winding.

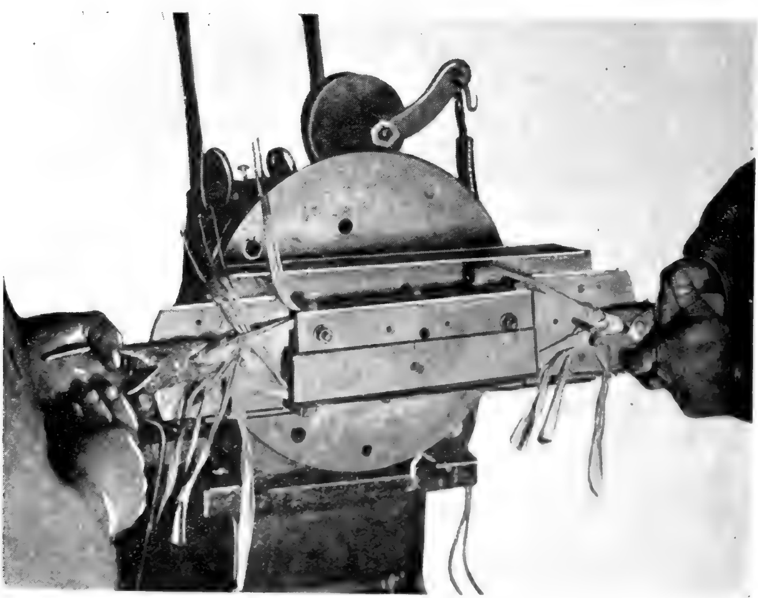


FIG. 337.—Forming Twist at Ends.

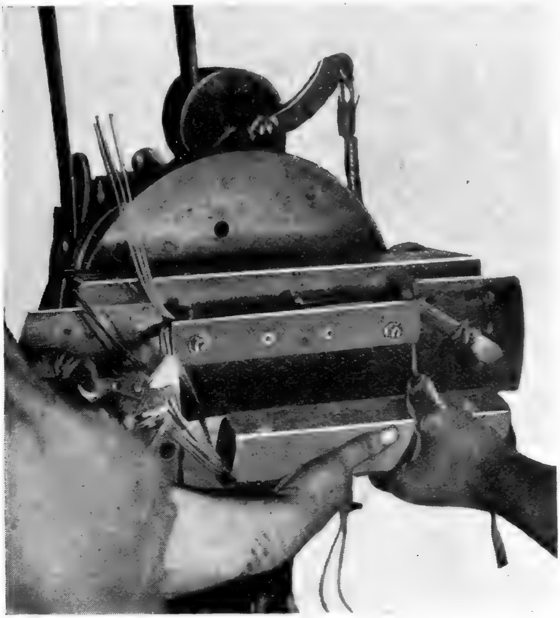


Fig. 338.—Spreading.

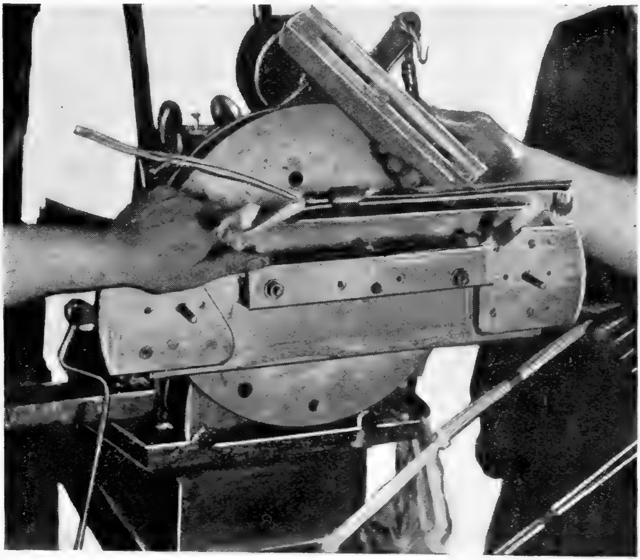


Fig. 339.—Removing from Form.

ponent coil of the triple coil separately upon a fibre-lined wooden form. These separate coils are afterwards assembled together to form the triple coil during the insulating operation. This winding form has the exact contour of the finished coil, and is fastened to a lathe head: the wire being wound directly off the reel on to this form, the shape of the coil being preserved up to the time of its

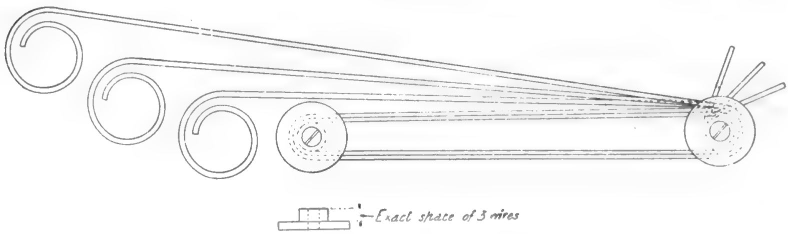


FIG. 340.—Winding Triple Coil.

being assembled together with the other two by means of metal clips, as previously described.

Fig. 341 shows the arrangement of the form, which consists of a wooden block made in two halves.

A type of metal form suitable for this class of coil is shown in

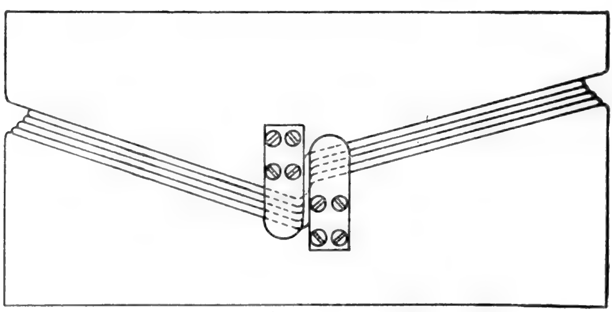


FIG. 341.—Winding Block for Wire Coils.

Fig. 342. This form is designed to produce factory coils ensuring an absolute fit the one into the other; it is made of special light and non-corrosive tough metal. The outer half can be released and the coil removed without the use of nuts or wrenches, which renders it quick in operation. For winding, the form is mounted simply on a winding head.

Having now dealt with the construction of winding forms and methods of shaping coils in general, and considered the application to two typical cases, we shall proceed to give some photographs of several armatures at different stages during the assembling of the finished coils on the armature, and we shall take the different types of winding separately and deal briefly with each.

Preparation of the armature body for receiving the coils:—The armature core should be prepared so that the coils can be readily assembled on it with a minimum of damage to the insulation. It is usual to run a file over the sharp corners of the teeth at the surface of the armature to take off all rough edges wherever the coils are likely to touch. Instead of using a file, the corners may be ground off with the aid of a small emery wheel. A convenient

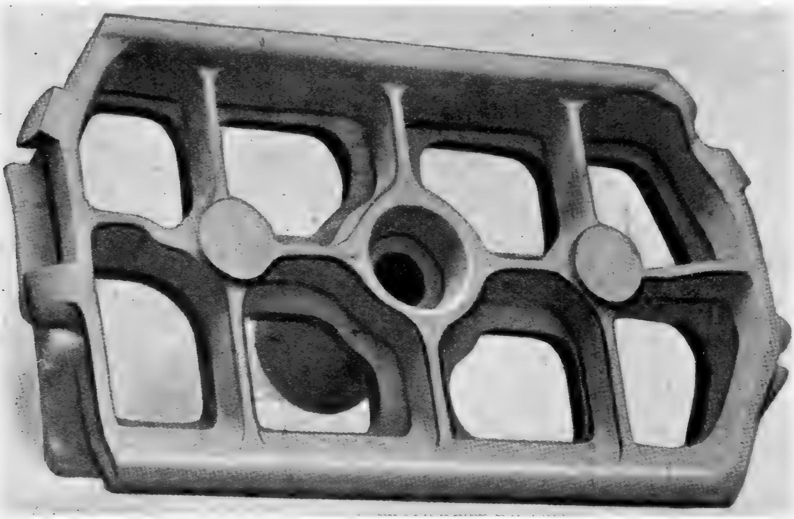


Fig. 342.—Metal Form for Standard Coils (American General Engineering Co.).

grinder made for this purpose by the Cleveland Armature Works is shown in Fig. 343. It consists of a portable emery wheel driven by a small electric motor and suspended from the ceiling for convenience in handling. Of course such work on the core increases the core loss, and is undesirable from that standpoint.

It is stated that this tool will work about ten times as quickly as the time taken by hand or with an ordinary file.

The next step is insulating the armature body. Fig. 344 shows a typical moderate-sized armature insulated and practically ready for winding. The insulation for the slots is cut up from the sheet into strips to the required width in a guillotine or hand shear, of the type shown in Fig. 345. The width of the strips must be sufficient to cover the contour of the inside of the slot, and to stand up an amount sufficient to overlap and cover the conductors at the mouth of the slot. The gauge-piece on the shear can be set so that all the strips are cut to exactly the same width.

Fig. 344 shows the slot insulation in place in nearly all the slots. The rings which project at each end of the armature spider for supporting the end portions of the windings are taped up. In small armatures, and in some of moderate size, where the end

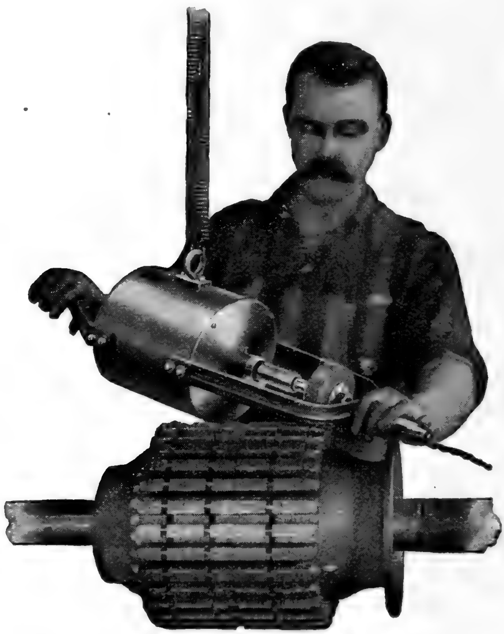


FIG. 343.—Portable Grinder (Cleveland Armature Works).

supports are made as a solid cylindrical shell, not being cored out of skeleton structure as in Fig. 344, they are insulated by binding them round with tape circumferentially, as is the case in Fig. 346. At the right-hand end of Fig. 344 there is seen a flange studded with projecting bolts, to which the commutator bush is bolted.

STRIP-WOUND LAP WINDINGS.

Fig. 346 illustrates an armature with about half the coils assembled in place in the slots. A few separate coils are shown in the foreground. The mounting of this armature for convenience in turning round is worth noting: each end of the shaft is

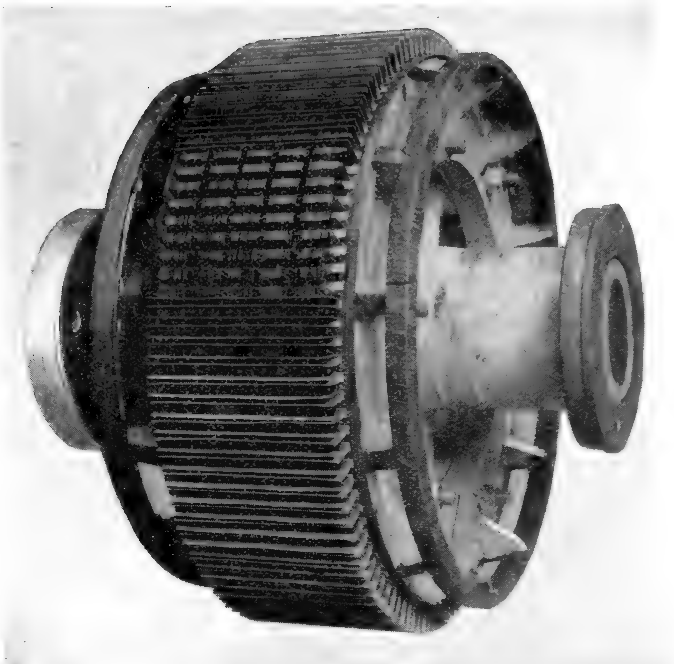


Fig. 344.—Armature Insulated and prepared for receiving Coils (British Electric Plant Co.).

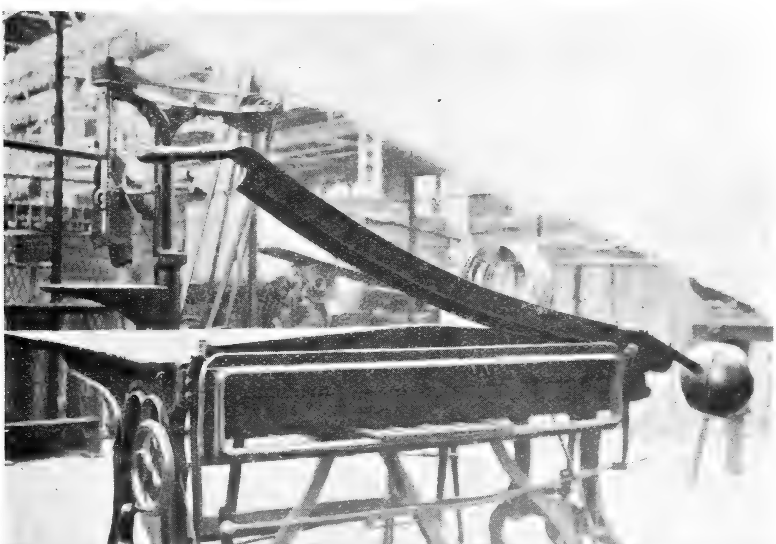


Fig. 345.—Hand-shear for cutting Sheet Insulation.

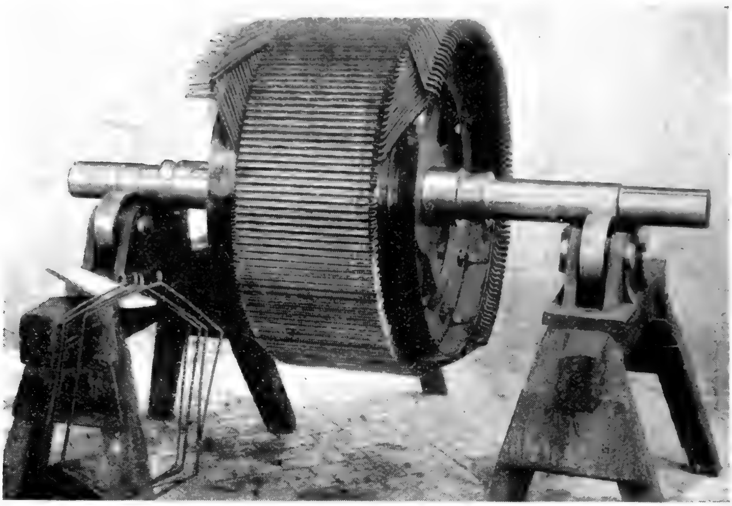


FIG. 346.—Assembling Strip-wound Coils (Alioth Co.).

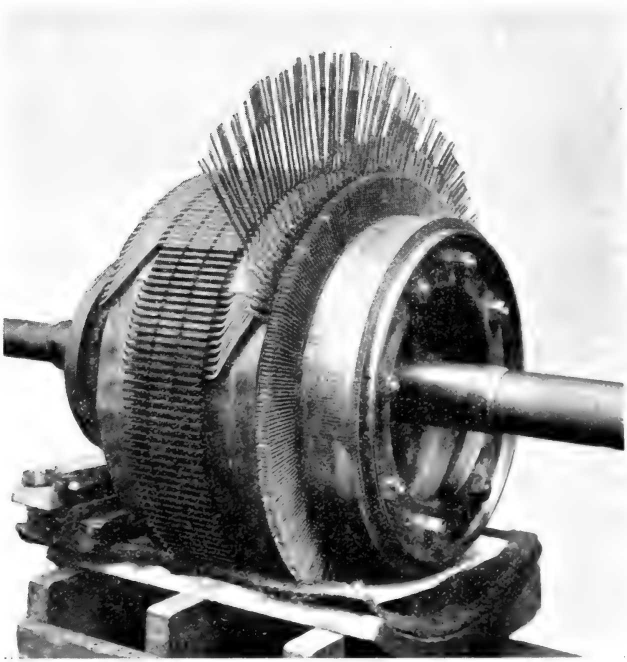


FIG. 347.—Assembling Strip Coils on Armature (Vickers, Sons & Maxim).

supported on a pair of wheels. Fig. 347 shows a similar armature with the commutator in place. The ends of the coils are bent up radially ready for attachment to the commutator lugs; there is

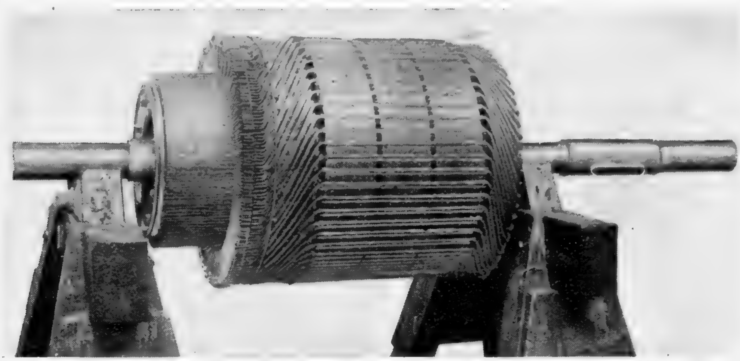


Fig. 348.—Coil Ends in place ready for Soldering Connections to Commutator (Vickers, Sons & Maxim).

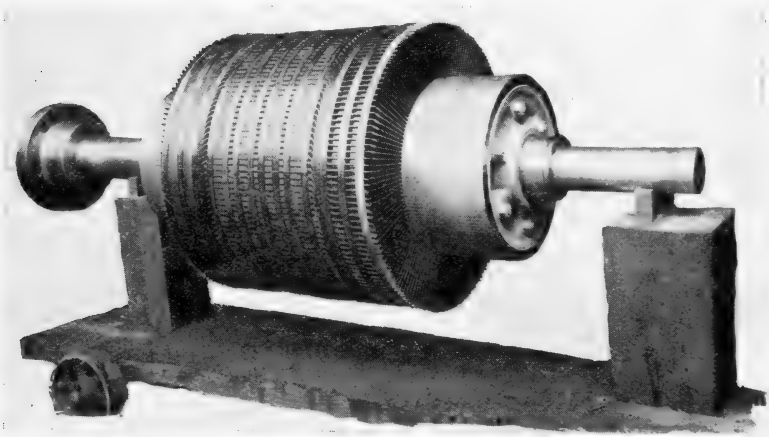


Fig 349.—Finished Strip-wound Armature (Bruce Peebles).

also visible the sheet of insulation between the upper and lower layers of the end windings.

Fig. 348 shows the ends of the coils bent down into the commutator lugs, and bound round with a piece of wire to hold them in place during the soldering of the joints. The joints are sweated up by heating the neck of the commutator lug with a small

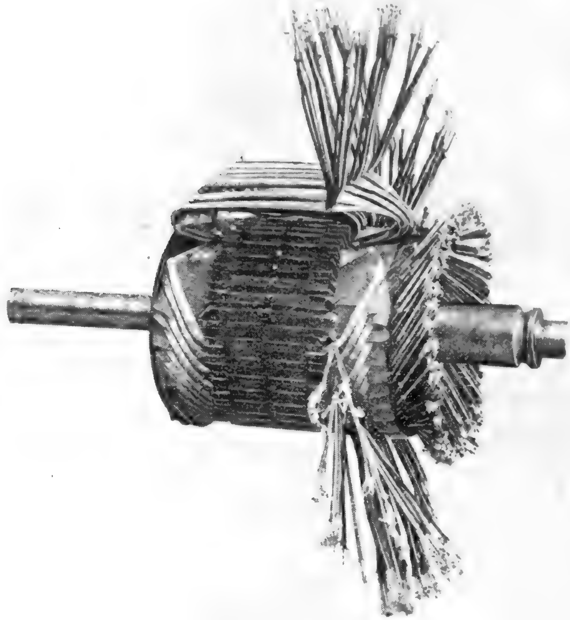


Fig. 350.—Assembling Wire-wound Coils (Lancashire Dynamo and Motor Co.).

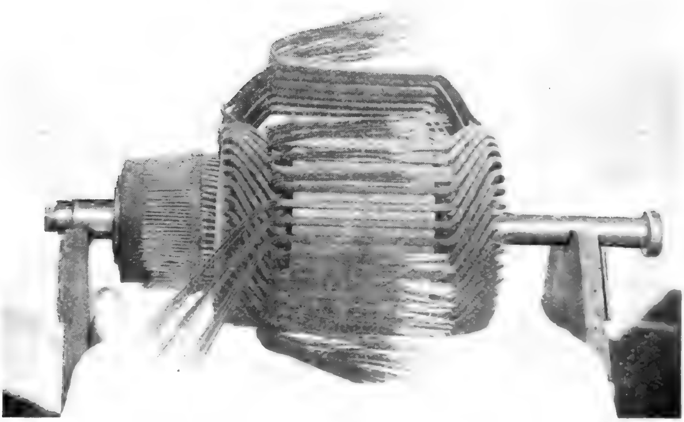


Fig. 351.—Commutator in place, with Coil Ends ready for Connection (Lahmeyer Co.).

pointed blast flame and a soldering iron applied at the top of the lug, running solder in from the top from a thin stick.

After soldering and finishing up the joints, which will be done by hand, the binding bands are applied over the end windings with a layer of sheet insulation in between. The projecting

Fig. 352.—Armature Coils assembled ready for Commutator (Vickers, Sons & Maxim).

edges of the slot linings are pared off, and binding bands put on round the armature core if these are required. After final machining of the commutator, the finished armature appears as in Fig. 349.

Wire-wound Coils.

Having prepared the armature core for receiving the coils, their assembling and connecting up is a similar process to assembling strip-wound coils, and the photos which we now give will be sufficient to illustrate this without much description. Fig. 350 shows the armature core with all the coils put on. The six coils at the top of the armature not right home are the first coils put on, and the upper sides of these are left up out of the slots until all the other coils are in place, as the bottom parts of these six slots have to be occupied by the lower sides of the last six coils to be assembled. When all the coils are assembled, the first coils can

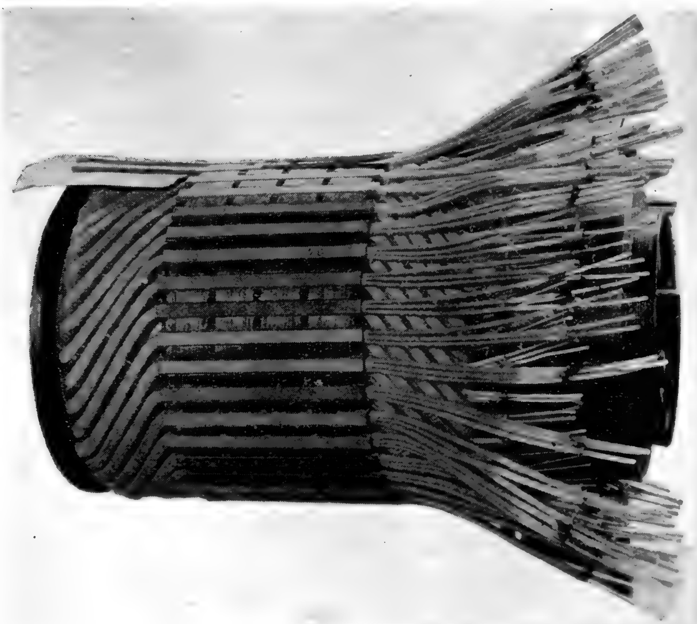


FIG. 353.—Inserting Slot Wedges (British Electric Plant Co.).

be put right home. One will note the pieces of linen placed between the ends of the adjacent coils, also the insulation between the upper and lower layers

Fig. 351 shows a similar armature; but here the commutator is in place, and the lower ends of the coils are in place in the commutator lugs.

In Fig. 352 a larger armature is shown, with all the coils in place ready for receiving the commutator and for connecting up.

Fig. 353 is the armature of a 4-pole machine with all coils in place and the commutator ready for sweating the coil ends into

Fig. 354.—Connecting Coils to Commutator (Vickers, Sons & Maxim).

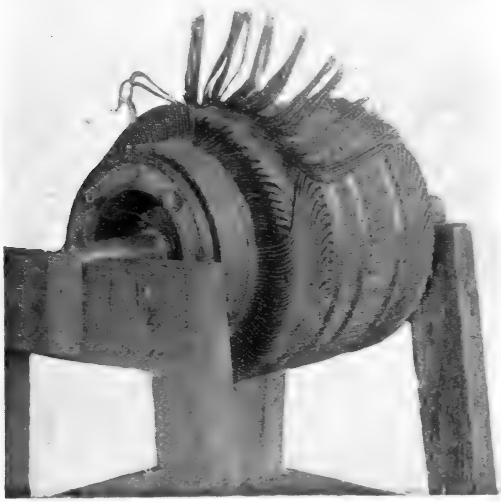


Fig. 355.—Armature with nearly all Coil Ends soldered to Commutator (Adolf Unger and A. V. Clayton).

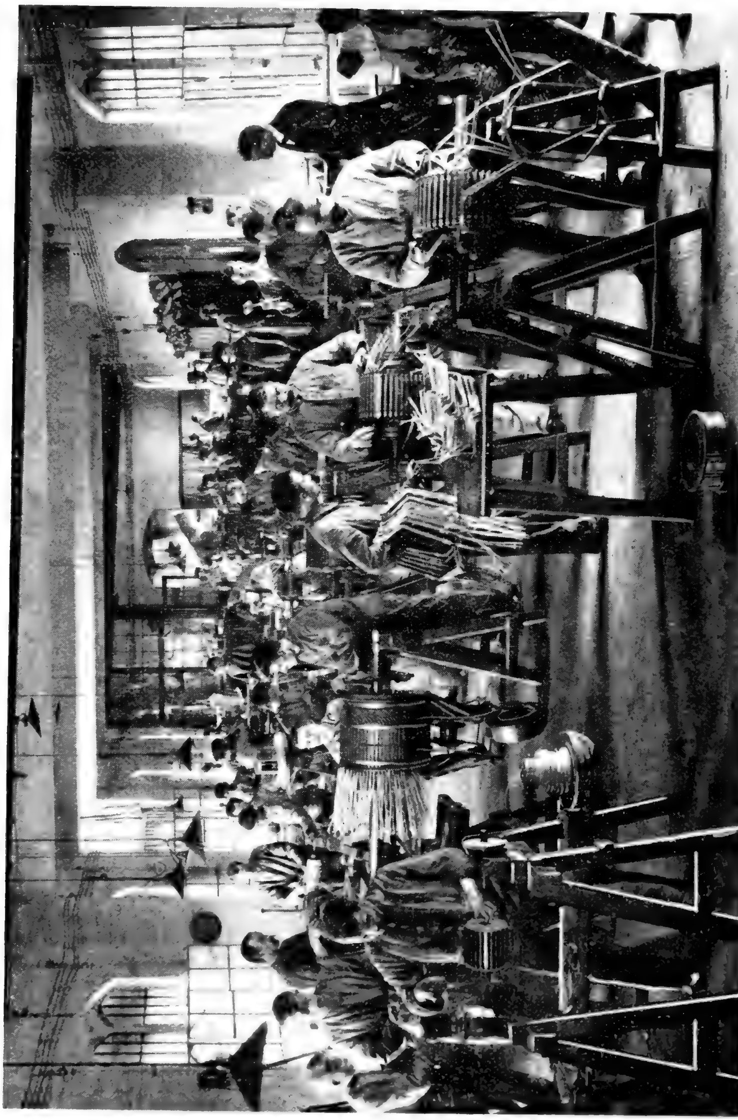


Fig. 356.—Lahmeyer Co. Continuous-current Winding Shop.

the commutator lugs. At the top of the armature the view shows the wedges being inserted for holding the coils into the mouth of the slots.

Fig. 354 is the armature of a 30-h.p. crane motor. Here half of the coil ends are brought down to the commutator, and the other half bent up out of the way ready for bringing down to the commutator.

Fig. 355 illustrates an armature in a nearly finished condition. The lower range of coil ends are all sweated in to the commutator

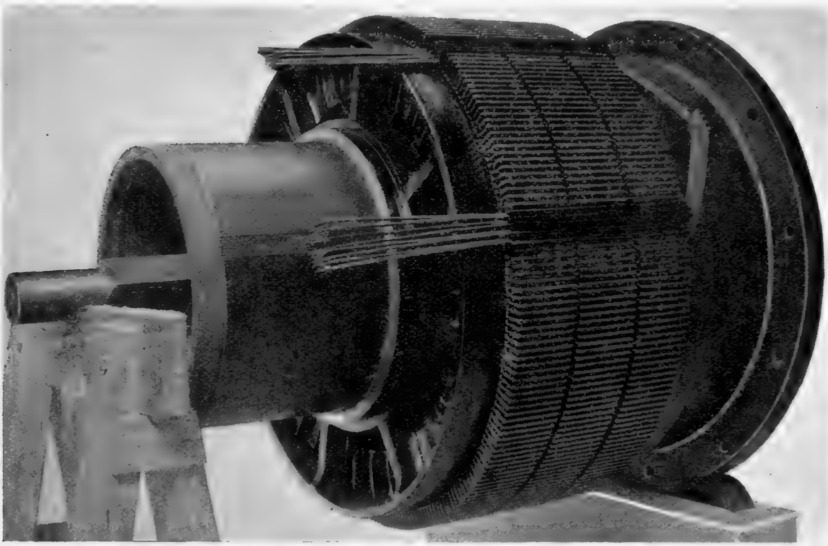


Fig. 357.—Wave-wound Armature with Four Coils in place (Bruce Peebles).

lugs, and nearly all the upper ends are also sweated in, as will be clearly seen.

After the coils are all assembled and connected up, they are trued up by rotating the armature in a lathe and holding a piece of chalk against the windings, which marks any coils projecting more than the others. These may be hammered into place with a fibre mallet, or a wood mallet and fibre wedge.

Fig. 356 gives a general view of a continuous-current winding shop, showing the assembling of form-wound coils.

Strip-wound Wave Windings.

We now give a few photos illustrating the stages in assembling wave-wound coils on the armature.

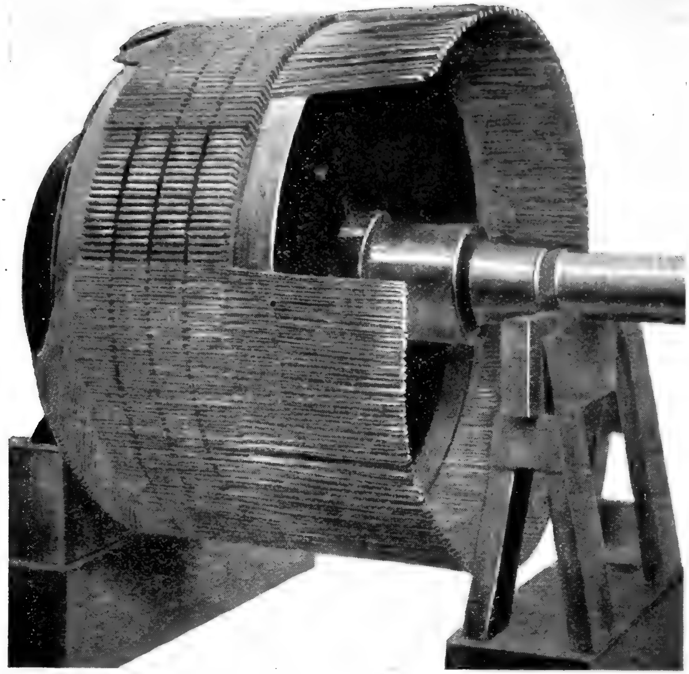


FIG. 358.—Assembling Wave-wound Coils (Bruce Peebles).

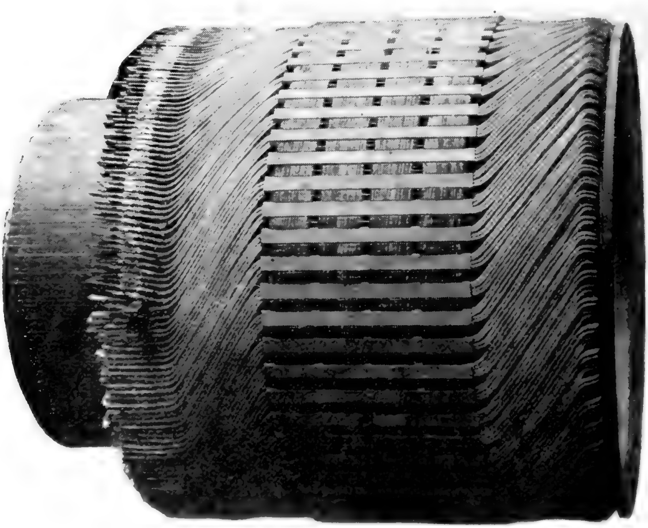


FIG. 359.—Wave-wound Armature with Coil Ends bent for connecting to Commutator (British Electric Plant Co.).

Fig. 357 shows four coils in place on a large armature, from which the shape of the coil element is clear.

Fig. 358 shows a similar armature with the greater number of

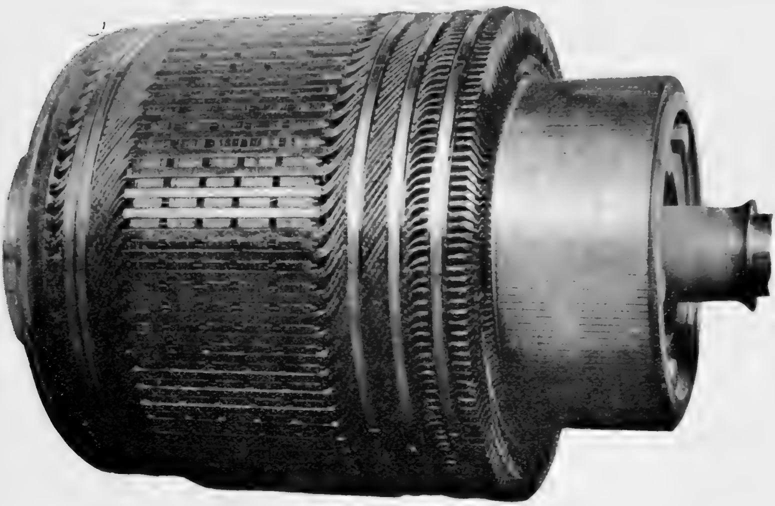


FIG. 360.—Finished Wave-wound Armature.

the coils assembled. In Fig. 359 we have all the coils in place, and the ends bent round and brought into the commutator lugs.

Fig. 360 illustrates a finished armature with a strip wave winding.

CHAPTER XII

THE WINDING OF ALTERNATING-CURRENT ARMATURES

In treating the subject of the winding of alternating-current armatures it will be convenient if we take them under the types as classified in Chap. IX., dealing with alternating-current armature winding diagrams.

In that chapter we gave a number of photographs of the various types of winding side by side with their winding diagrams, and from these a good deal may be learnt respecting the construction and the finished appearance of the windings. In the present chapter we shall consider the methods of carrying out the various windings.

In Chap. IX. we classified the alternating-current windings under six headings:—

A. Spiral coil.
B. Lap coil.
C. Wave.
D. Retrogressive wave.
E. Skew coil.
F. Short coil.

The difference between these types is seen on reference back to Fig. 236.

A. *Spiral-Coil Windings.*—Spiral coils may be either hand-wound or form-wound, generally according as the slots are totally or semi-closed, or wide open.

The question is also affected by whether the coil is a single, double, or triple coil (see Fig. 237), as a triple coil, if form-wound, would require three different sized forms, and a quadruple coil four forms, and so on. For this reason if the coil is more than a double coil, it will usually be hand wound.

Hand Winding.—We shall consider first wire windings by hand, and then strip windings.

The common method of wire winding with semi-closed or tunnel slots may be designated "pin-winding." In this method the slots are filled with a number of wire pins—of diameter equal to the diameter of the covered wire with which the armature is being wound, and equal in number to the number of conductors required ultimately in the slot.

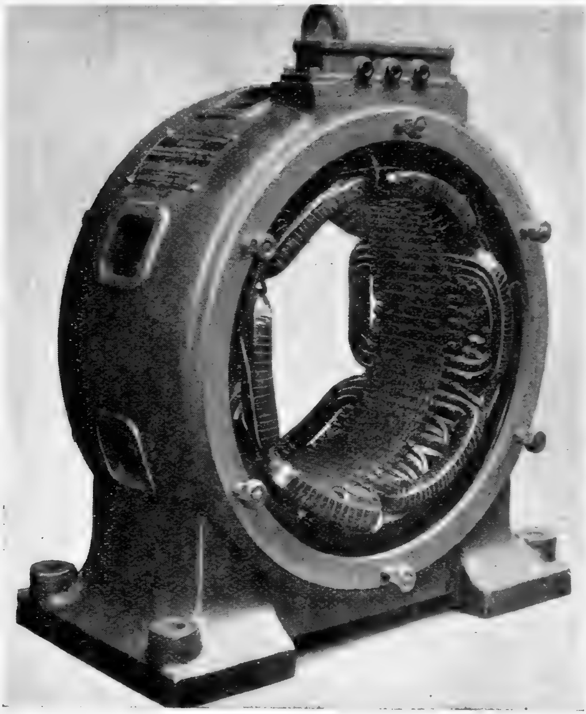


FIG. 361.—Wound Stator for Induction Motor. Eight-pole, Three-phase, Half-coiled, Triple-coil, Three-slot, Spiral-winding (Scott & Mountain).

The pins project a few inches out of the slot at each end of the armature, and the process of winding consists in pushing each pin out of the slot with the end of the wire and so proceeding until all the pins have been extracted, and the slot is filled with the wire conductors.

It may be well to take a concrete example, and for this let us consider an 8-pole 3-phase stator having 72 slots and 8 conductors per slot, the coils to be laid up in two ranges. We have seen on p. 191 that a 2-range 3-phase winding *must* be half coiled ; hence the number of coils per phase is half the number of poles, *i.e.* $\frac{8}{2}=4$ coils per phase, and $4\times3=12$ coils in all. The number of slots per pole per phase is $\frac{72}{8\times3}=3$; or 9 slots per pole.

From Table XIV., p. 203, we see that a half-coiled winding having 3 slots per pole per phase has triple coils; or, from Table XV., a

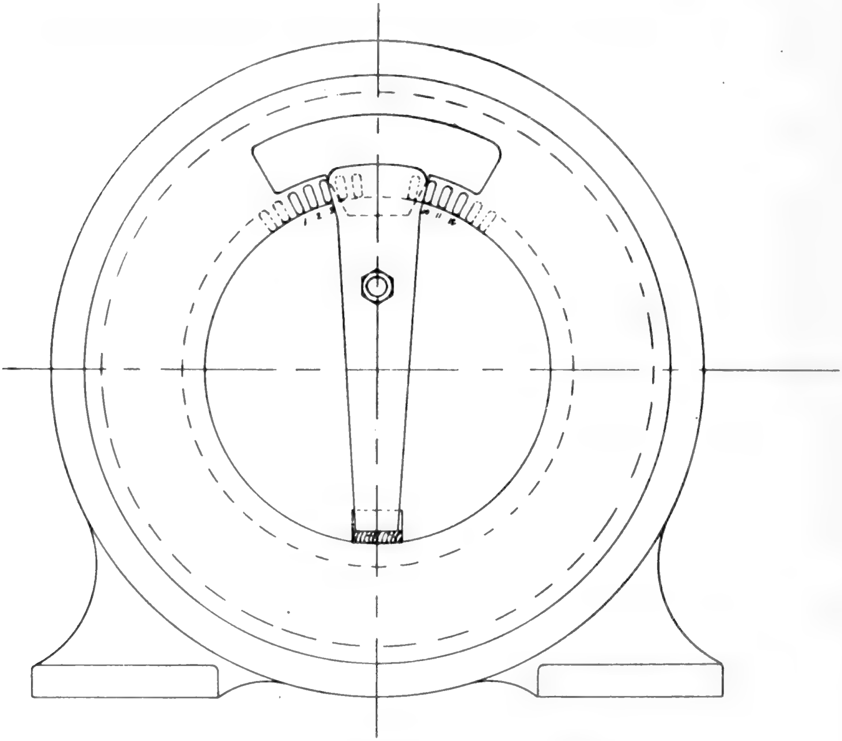


FIG. 362.—Winding Block for Hand Winding.

3-phase half-coiled winding having 9 slots per pole has triple coils. Hence the coil must cover 3 slots on either side, as it is a triple coil (see definition on p. 198).

A view of a stator with a winding corresponding to the above conditions is given in Fig. 361, and with such an armature we are now dealing.

The winding diagram for this armature is given in Fig. 244 on p. 207. Taking coil No. 1, we have to wind from slot No. 10 to slot No. 3, then taking in slots Nos. 11, 2, 12, and 1 in order.

The ends of the coils are formed over a wooden block, which is shaped and mounted on the job in the manner shown in Figs. 362 and 363.

A slab of fibre between the winding block and the core end flange distances the coil from the end flange. The block for this case should just cover 6 slots which are left open for the front range coils.

The back range coils are wound first.

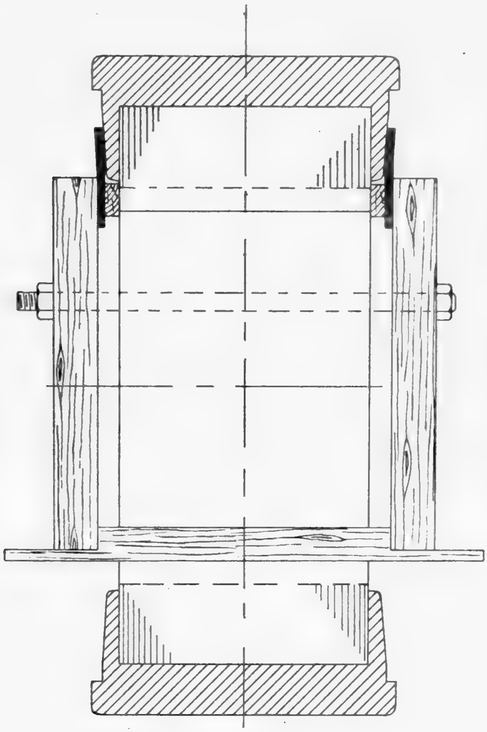


Fig. 363.—Arrangement of Winding Blocks for Hand Winding.

The slot insulation is inserted, in the case of semi-closed slots or tunnels, by pushing the tubes in from the end of the core.

Slots Nos. 10 and 3 are now filled with 8 pins each, as there are to be 8 conductors per slot.

Let us suppose, for instance, that the winding is to be done with S.W.G. 11 : the diameter of S.W.G. 11, bare, is 2·95 mm.; and double cotton covered, 3·20 mm. The pin should be of diameter 3·20, and the nearest standard wire to this is S.W.G. 10.

A length of wire is cut off the reel sufficient to wind one coil; the length may be arrived at from the number of turns and the mean length of turn. The pins are then displaced in the order indicated in Fig. 364, commencing with No. 1. The whole length of wire runs through the slot each time a pin is displaced.

When slots Nos. 10 and 3 have been filled, the job appears as in Fig. 365. The pins are now put into slots 11 and 2, and when these are finished the state of affairs is as in Fig. 366.

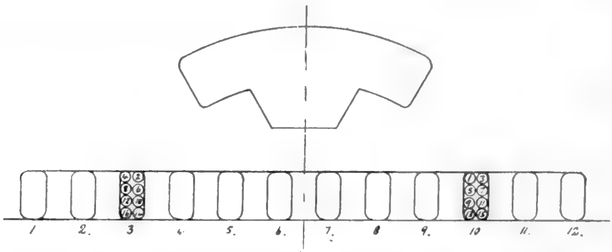


Fig. 364.—Arrangement of Pins in Slots, showing Order of Winding.

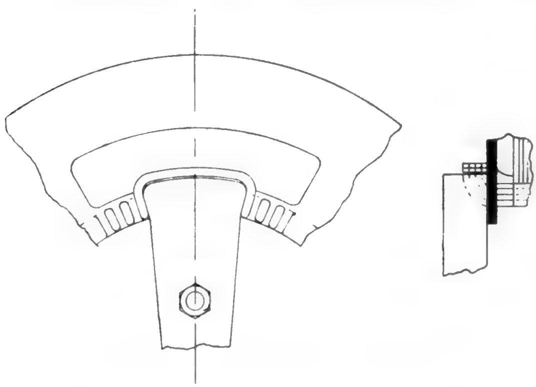


Fig. 365.—Slots 3 and 10 Wound.

Slots 12 and 1 are next taken in, and when these are finished and the blocks cleared away the coil appears as in Fig. 367, and the ends are marked S and T in accordance with the convention of Chap. IX. One may see how the actual shape and form of the winding of this coil corresponds to the diagram of the type in Fig. 207.

The stator will now be moved through an angle of 60° so that the block may be set up in a vertical position ready for winding the next adjacent coil in the back range. The stator is repeatedly turned in this way until the whole of the six coils in the back range have been wound, after which they may be taped up and varnished, giving the appearance shown in Fig. 368. One range of coils is now completed and the block is set up for the first coil of the second range.

The second range may be bent up after leaving the slots in a plane parallel to the first range, as in Fig. 230, *d*, or the ends of the coils may project out cylindrically as in Fig. 230, *c*, Chap. IX.

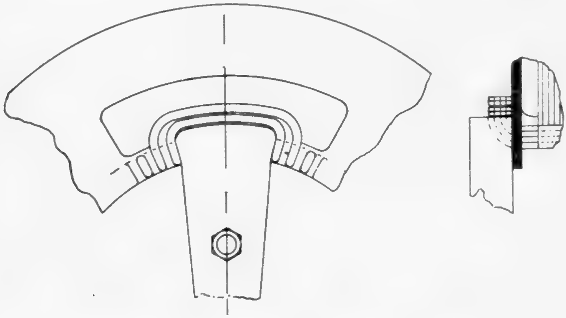


FIG. 366.—Slots 3 and 10, 2 and 11 Wound.

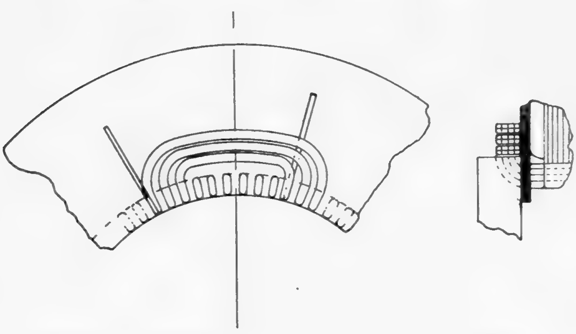


FIG. 367.—Slots 3 and 10, 2 and 11, 1 and 2 Wound.

Taking first the case where the coils are bent up parallel, and the block is rigged up in the manner of Fig. 369, the front range of coils is wound and finished in exactly the same way as the previous range. The phases are next connected up according to the diagram in Fig. 247.

The connections between the coils of each phase may be made to lie against the core end flange, above the ends of the coils. If the winding is a 3-range winding, the winding blocks are packed out still further for the third range, which is then laid up in front of the other two ranges and wound in precisely the same way.

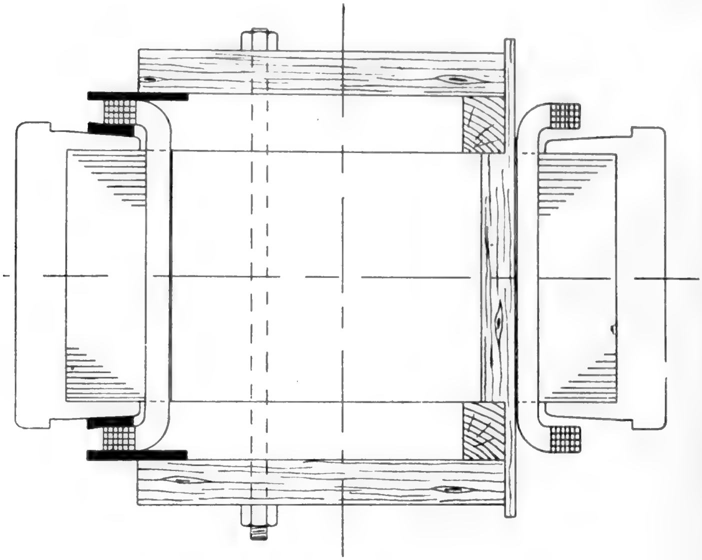


Fig. 369.—Arrangement of Winding Blocks for Front Range Coils.

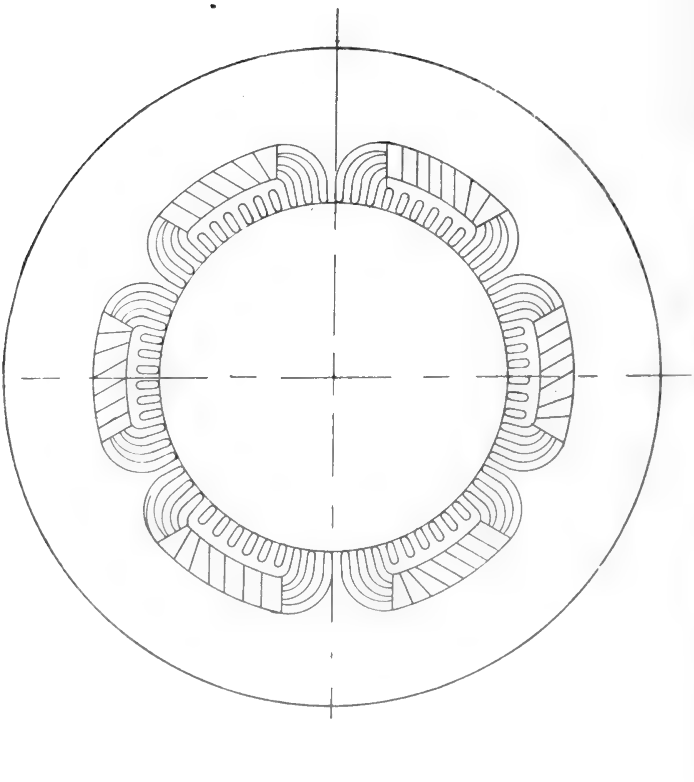
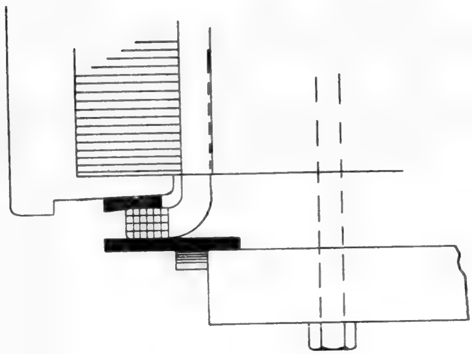


Fig. 368.—Stator with Back Range of Coils completed.



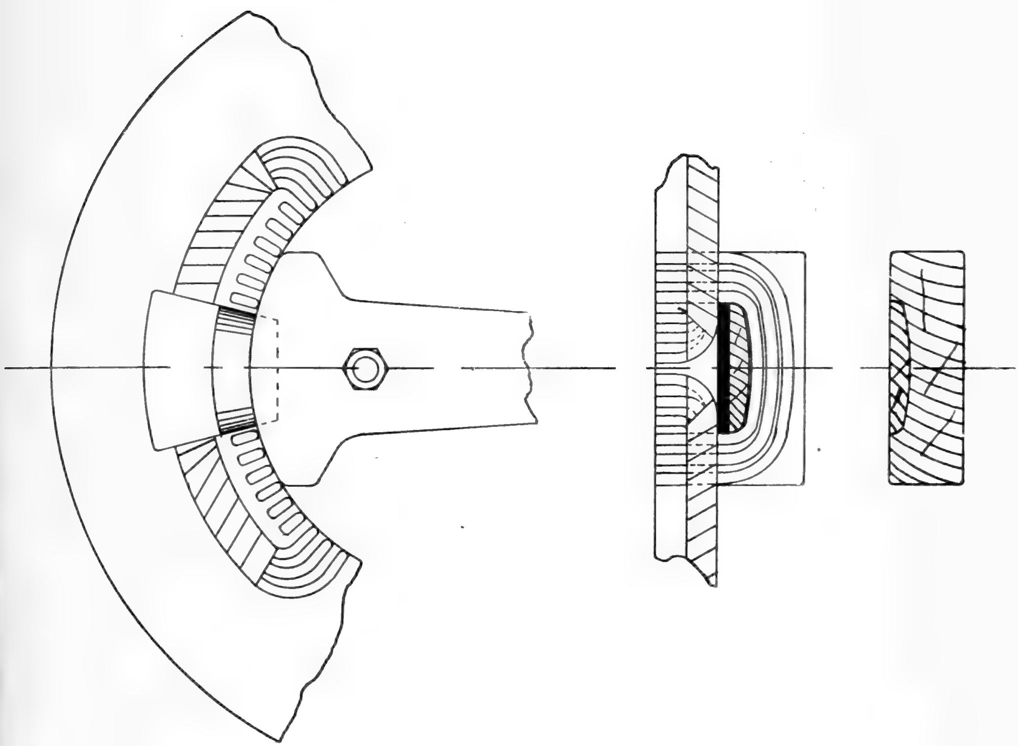


FIG 370.—Arrangement of Winding Block for Straight Coils.

In winding by this method, care should be taken that the end of the wire which pushes the pins out of the slot is well rounded with a file, since, if left rough, it will damage the insulation of the wires already in the slot.

In the case we have considered, the ranges are both bent back as in Fig. 230, *d*. If the second range is to project straight out, as is actually the case in the stator shown in Fig. 361, the coils may be wound over a block shaped in the manner indicated by Fig. 370, from which the method of winding will be apparent. Fig. 371 shows a coil in process of winding over a block of this form.

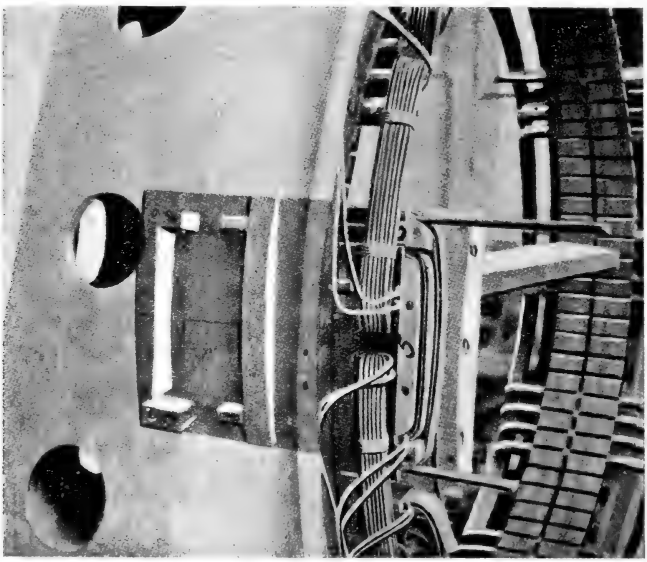


FIG. 371.—Hand Winding of Alternator Coils (Alioth Co.).

The straight coils may often be wound without the aid of a block, by shaping them simply by hand. This is easier if there are few conductors per slot, and the conductor is a fairly big wire which will remain in the shape to which it is bent by hand.

Fig. 372 illustrates the winding of a 3-phase, whole-coiled, double-coil winding in three ranges. The photo shows two ranges completed, and the first coil of the third range in process of winding. The winding is a whole-coiled winding with 6 coils per phase, and hence 6-pole, and 18 coils in all.

Table XIV. on p. 203 shows that the number of slots per pole per phase must be 4, and hence the total number of slots is $4 \times 3 \times 6 =$

72. The method of supporting the winding block is rather different from the methods described above.

The methods in Fig. 371 and Fig. 372 are more convenient for large armatures, whereas the previous methods apply to small armatures and induction motor stators. The pins projecting from the slots being wound can be seen in Fig. 372.

FIG. 372.—Winding Three-phase, Whole-coiled, Double-coil Winding in Three Ranges (Two Ranges completed)—(Bruce Peebles).

On p. 192 and Fig. 231 there was given an example of a 2-range winding with an odd number of coils, which necessitated a bent coil. Such a coil may be shaped by hand; but this is rather difficult, and a block suitable for winding the coil is outlined in Fig. 373. The bend is formed round a projection on the winding block. In carrying out the winding, all the back range coils are wound first and then the bent coil, and lastly the front range of coils. Thus in Fig. 373, coils *d*, *a*, are wound first, and then all the back range coils; next the bent coil *c*; and lastly *e*, *b*, and the rest of the front range.

When the method of hand wire-winding is applied to rotating armatures or wound rotors for induction motors, the coils cannot

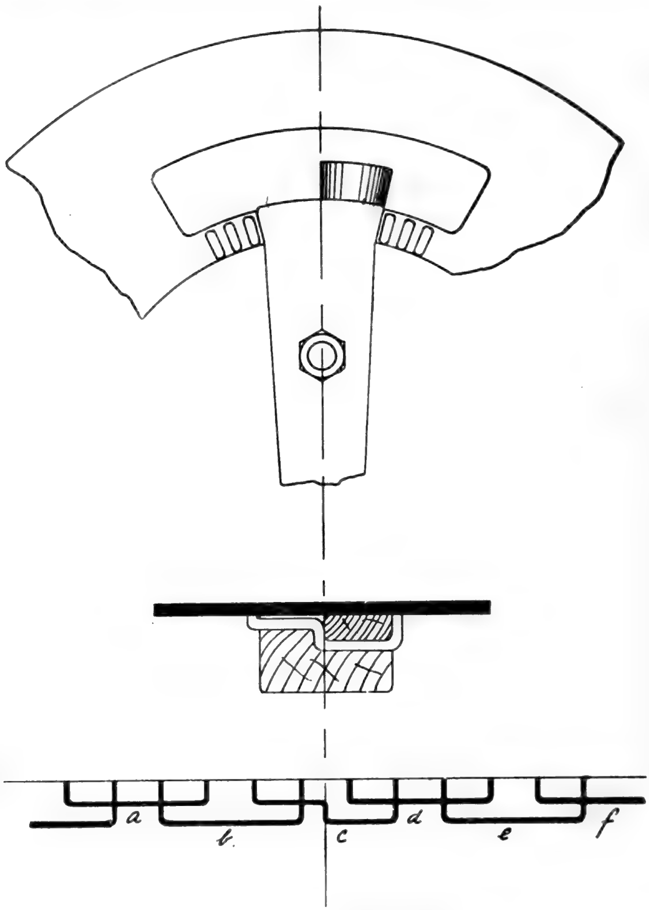


Fig. 373.—Block for shaping Bent Coil.

be shaped over a block, and the shaping has to be done by hand. The ranges are laid out in the same way as above. A finished rotor of this type is shown in Fig. 374, which is 4-pole, 3-phase, half-coiled, triple-coil, 3-slot, spiral winding in two ranges.

Figs. 375 and 376 illustrate a similar rotor at two stages during the winding. The coils in these cases need to be secured

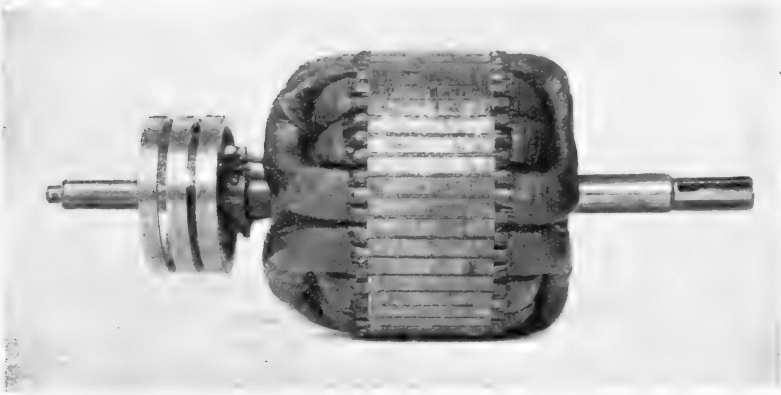


FIG. 374.—Wound Rotor for Induction Motor (British Thomson Houston Co.).

FIG. 375. —Induction Motor Rotor Winding with the Back Range of Coils in place (Adolf Unger, A. V. Clayton).

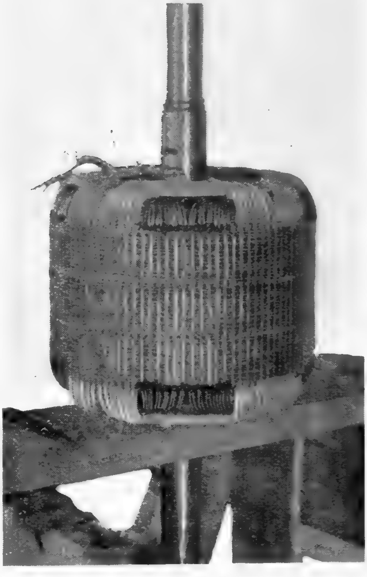


FIG. 376.—Rotor Winding with both Ranges Wound (Adolf Unger, A. V. Clayton).

against centrifugal force, and in the rotor shown in Fig. 374 this is effected by binding them on to an iron ring with cord or tape in the manner of Fig. 377.

Another method is to embrace the coils with straps of sheet metal bolted together through the inside of the rotor, or screwed on to the rotor end flanges in the way shown in Fig. 378.

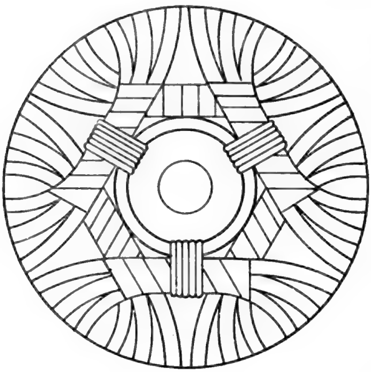


Fig. 377.—Methods of securing Rotor Coils.

The second method of winding with wire in semi-closed slots consists in slipping the wires one at a time through the mouth of the slot, as in Figs. 379 and 380. The slot opening must be sufficiently wide to admit the covered wire without damaging the insulation, which is closed over as in Fig. 381.

When the wire is small, the end portions of the coils when wound in this way are not usually formed over a block; but the wire is fed direct off a shuttle into the slot, and the coils shaped by hand.

This method also adapts itself to form winding, as the coils may be wound on formers; and if they are not taped or bound up, the wires can be slipped into the slot one at a time and the end parts of the coils assembled into shape when the slot is filled with wires.

Messrs Siemens Bros. have taken out a patent (No. 2196 of 1903) on this method, of which Figs. 382 and 383 show the principle. Here the coil is first wound on a former, and one side bound round temporarily with a piece of tape or a clip of lead to keep the coil intact, while the conductors on the other side are being slipped into the slots as in Fig. 383. Windings of this sort have, however, been extensively used years ago.

A patent was taken out by W. B. Sayers in 1904 (No. 12,801), by which form-wound coils may be employed with semi-closed slots, the substance of which is illustrated in Fig. 384. As shown, alternate teeth, 1, are made detachable from the body of the armature core, with which the other alternate teeth, 3, are made in one piece. The detachable teeth are retained to the core in channels 4. Fig. 384 shows one method of securing these teeth, the stampings on each side of the ventilating duct, 10, being spaced by brass plates, 11, 13, and with distance pieces, 14, between them.

To facilitate insertion each tooth stamping may be slightly bent along its axis and flattened when pressed into position. The coils may thus be form-wound and assembled on the armature before the detachable teeth are inserted.

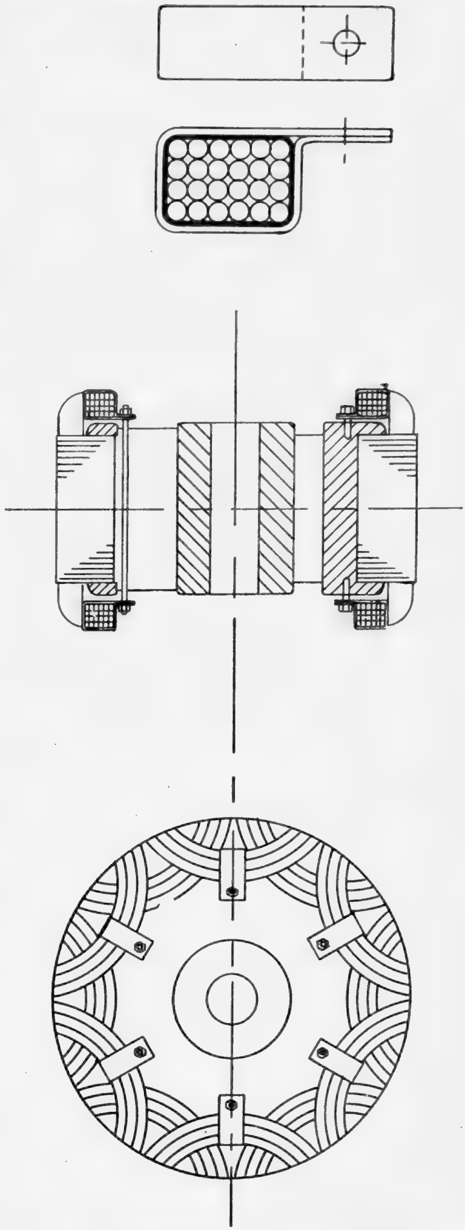


Fig. 378.—Methods of securing Rotor Coils.

Fig. 385 and 386 give general views of the alternating-current winding shop of Messrs Lahmeyer's works.

All the stationary armatures visible in this illustration are being hand wound, and shaped by hand with the aid of mallets and winding wedges. It will be noted that the coils in process of winding are in each case at the bottom part of the armature. This is the most convenient position for hand winding without a block; but when the coils are wound over a block, it is most convenient to wind them at the top of the armature, as in Fig. 372

Fig. 385 also shows the common types of reels in use for holding the coils of wire during winding.

Strip-wound Coils.—When the conductor consists of a braided strip the coils may be wound by hand, either over a winding-block,

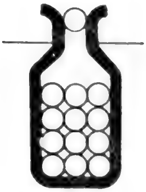


Fig. 379.

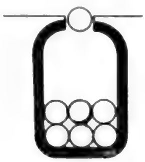


Fig. 380.

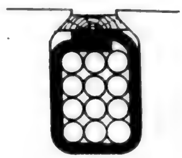


Fig. 381.

Hand Winding by slipping Conductors through Slot Mouths.

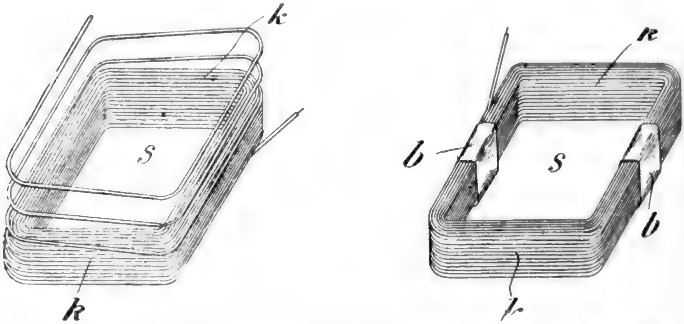


Fig. 382.—Siemens' Form-wound Coil for Hand Assembling in Slots.

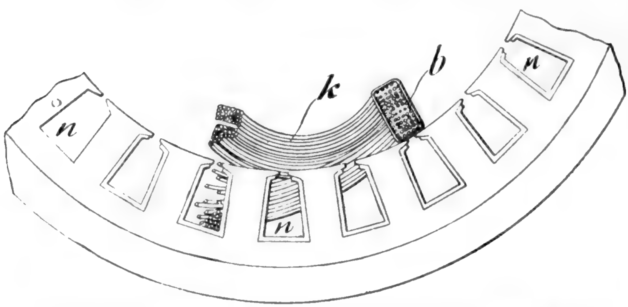


Fig. 383.—Assembling Form-wound Coil in Semi-closed Slot.

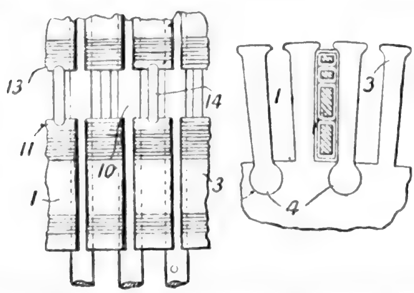


Fig. 384.—Sayers' Winding for Form-wound Coils and Semi-closed Slots.

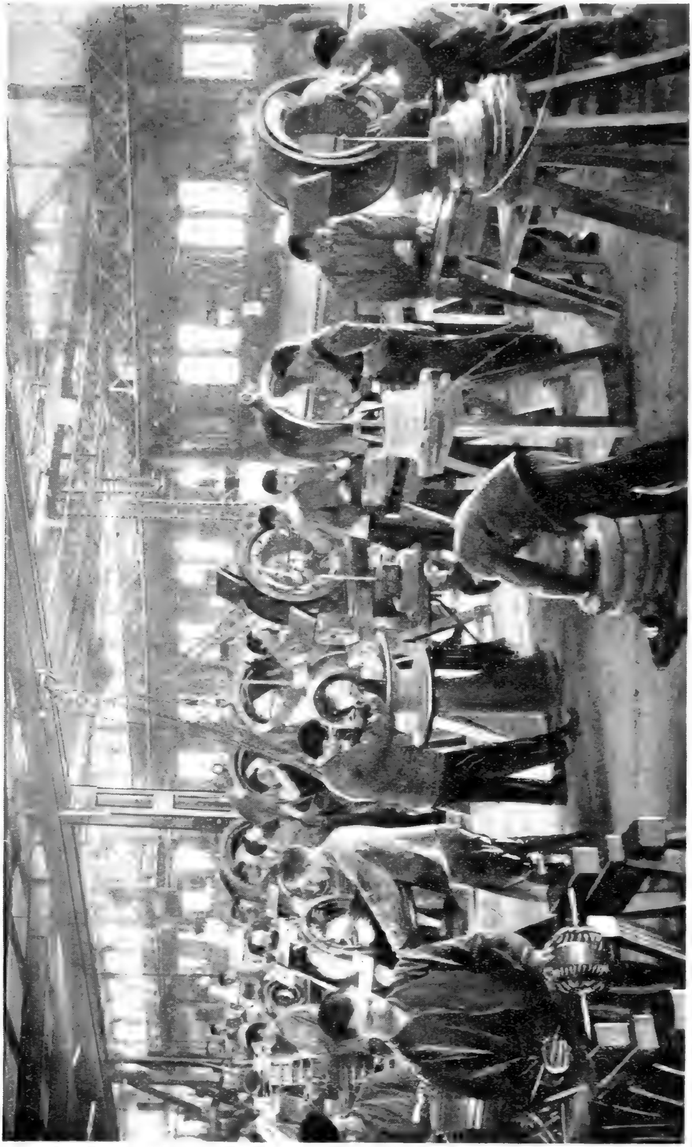


Fig. 385.—Lahmeyer Co. Alternating-current Winding Shop.

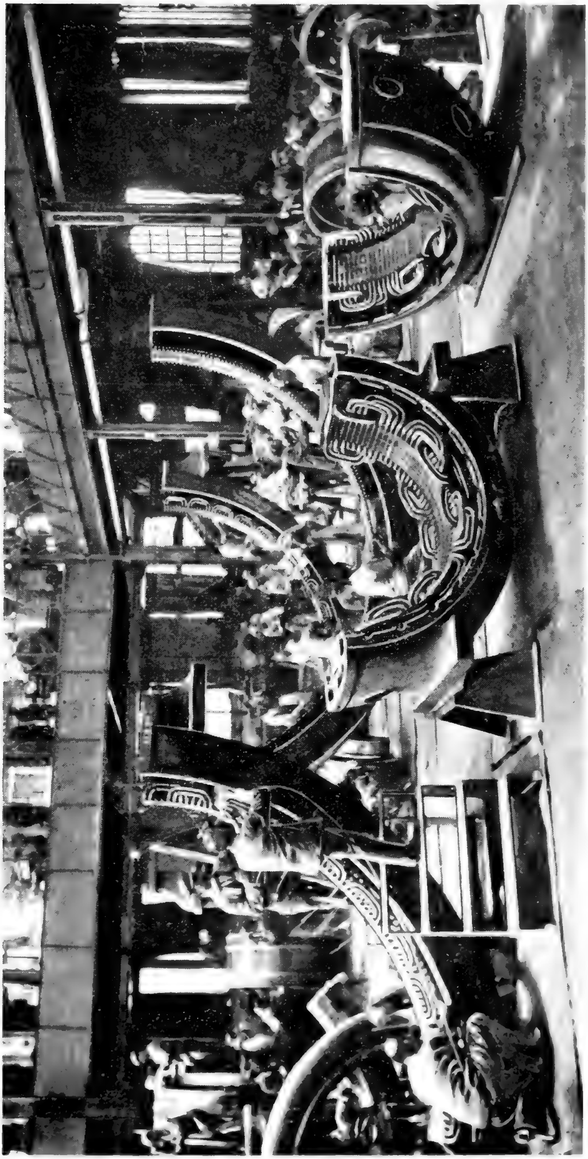


FIG. 386.—Lahmeyer Co. Alternating-current Winding Shop.

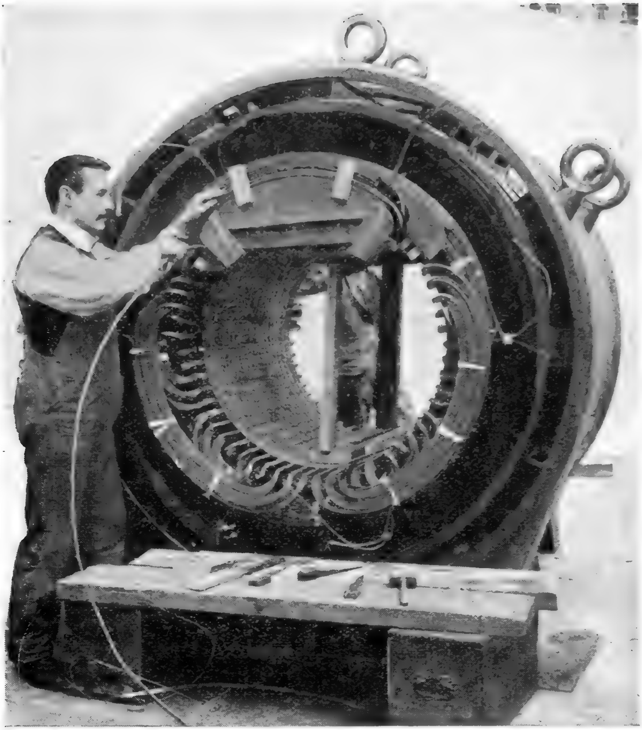


FIG. 387.—Winding 1000 k.w. Four-pole Turbo Alternator (Bruce Peebles).

FIG. 388.—Armature of 1000 k.w. Alternator (Bruce Peebles).

or shaped by hand in the same way as wire windings, except that pins would not be employed.

Fig. 387 shows a 1000-k.w. turbo-alternator armature being wound. The winding is a 4-pole, 3-phase, half-coiled, quintuple-coil spiral winding in two ranges.

By extending Table XIV. on p. 203, we find this winding to have 5 slots per pole per phase, which will be seen from Fig. 387 to be the number of slots covered by one side of one coil.

The total number of slots is thus

$$5 \times 3 \times 4 = 60.$$

There are 2 coils per phase and 3 in each range, making 6 coils in all. The slot contains 6 conductors wound flat, one above the other.

The winding block is similar to that used in the previous cases,

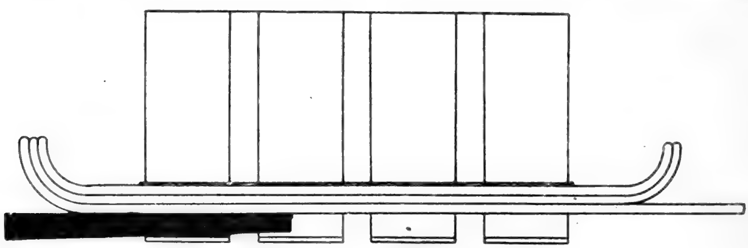


FIG. 389.—Winding Strip Coil.

but, instead of the pins used in wire windings, the conductor is held in a slot after threading it through by means of a wedge of fibre or wood in the manner of Fig. 389. This wedge is withdrawn from the slot each time a conductor is threaded through, and inserted after each conductor is in place until the slot is filled.

Fig. 388 shows the finished armature.

Fig. 390 shows an instance of strip-wound coils with the strip on edge in the slots. The coils are shaped by hand, and bent back with a mallet against a wooden backing which will be seen at the front end of the armature core, and which is withdrawn when the coil is finished. It is not easy to hand-wind strip on edge in this manner if the strip is very wide, owing to the difficulty in bending it on edge at the ends. If the coils are straight and not bent back, the difficulty is eliminated; but with a 2-range (or 3-range) winding one range at least must have its coils bent back.

A view of a finished armature, with coils wound with strip on edge in the slots, is given in Fig. 391.

The winding is a 20-pole, 3-phase, half-coiled, quadruple-coil, spiral winding in 2 ranges. For a half-coiled winding the number of coils per phase will be $\frac{20}{2}=10$ per phase, or $10 \times 3 = 30$ coils in all—*i.e.* $\frac{30}{2}=15$ coils in each range.

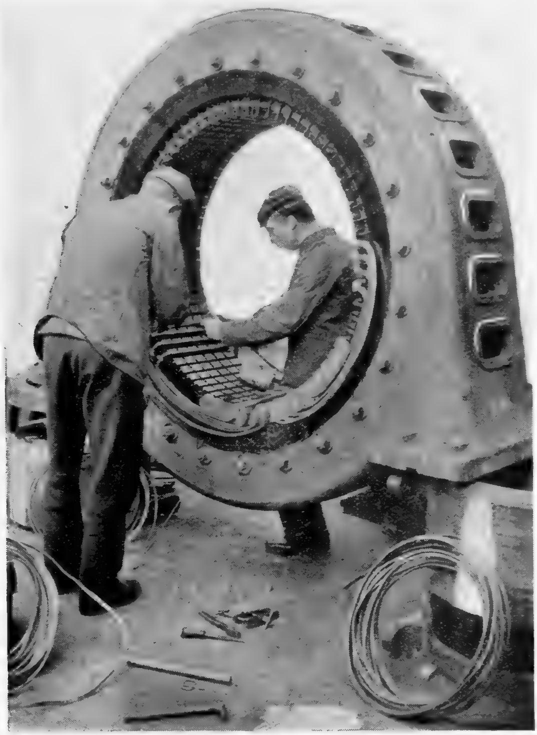


FIG. 390.—Winding Armature with Strip on Edge (Mavor & Coulson).

Table XIV., p. 203, gives us 4 slots per pole per phase, and hence the total number of slots is $4 \times 3 \times 20 = 240$ slots.

For example of finished 3-range windings we may refer back to Figs. 253 and 257 in Chap. IX.

Form-wound Spiral Coils.—As stated at the beginning of this chapter, form-wound coils are not desirable for coils other than single coil or double coil at most, owing to the number of formers required.

Where the conductors are wire or fairly small strip (with several per slot), the coils are formed on a simple bobbin block similar to the bobbins used for rectangular field coils.

Figs. 392 and 393 illustrate suitable formers for straight and bent coils.

With form-wound coils wide-open slots are necessary, and the question of open *v.* semi-closed or tunnel slots is not simply dependent on the first cost of winding.

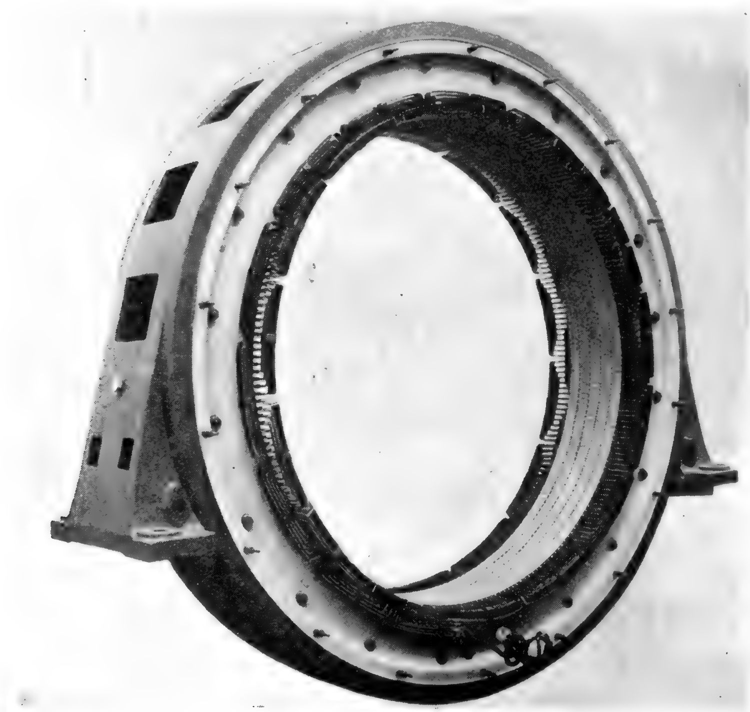


Fig. 391.—Strip-wound Armature (Bruce Peebles).

So far as first cost goes, the form-wound coil is undoubtedly considerably cheaper, but hand winding possesses superiority in other respects. Prominent among these is the matter of slot insulation. With open slots and form-wound coils the slot insulation must take one of the forms shown in Figs. 394 to 397. Each of these has the drawback that the insulating tube has a joint in it, and at this point the insulation is weak.

This is of considerable importance in high-voltage machines, but with low-voltage machines having one or two conductors per

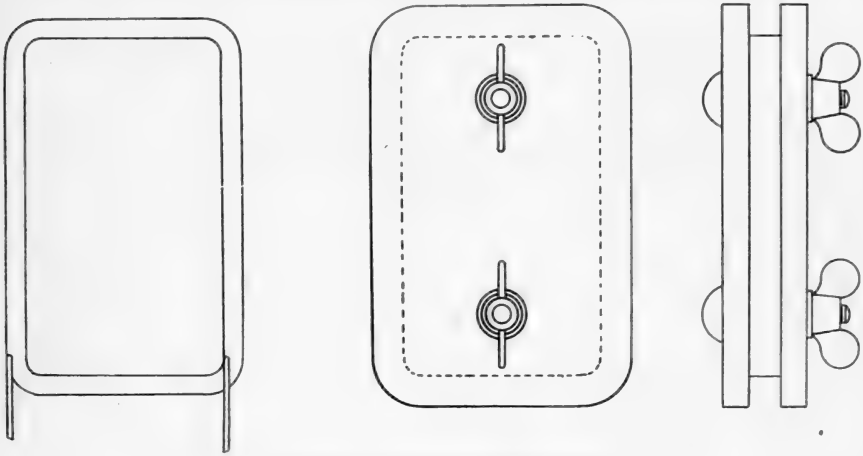


FIG. 392.—Form for Straight Coils.

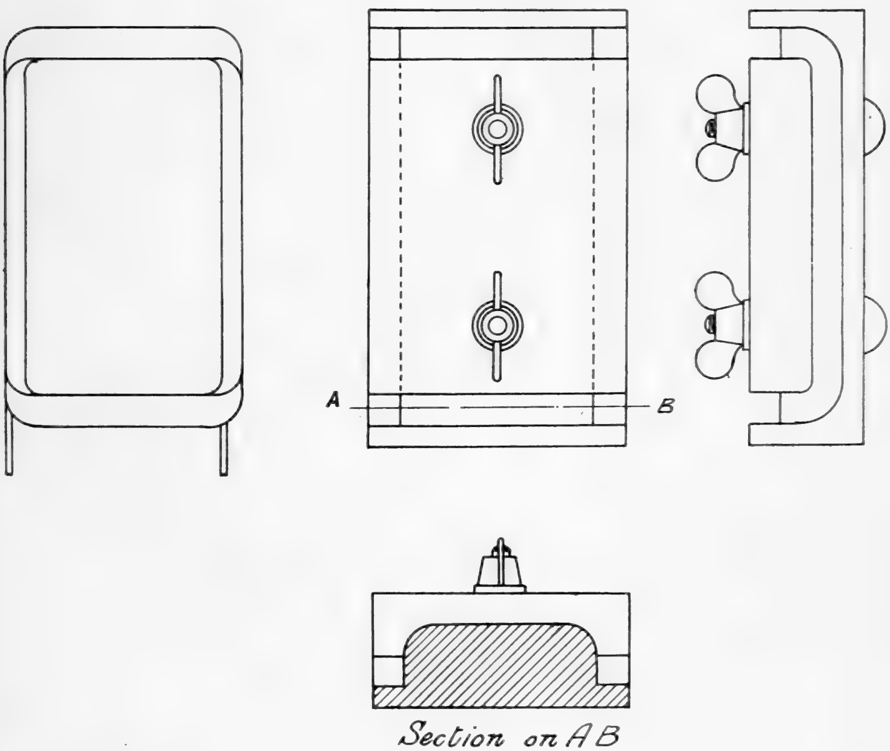


FIG. 393.—Form for Bent up Coils.

slot, it is not serious. These latter, however, are usually carried out as bar windings, and, with such, semi-closed or tunnel slots can be used without disadvantage.

A better alternative is Fig. 397; but here the double thickness of insulation at the mouth of the slot results in a considerable loss of space, and low space factor in the slot.

With hand windings the slot lining may consist of a seamless tube of insulation moulded and pressed into one piece, which renders it equally reliable at all points.

A further point in connection with Figs. 395, 396, and 397 is that the insulating tubes have to be opened out to admit the coils, which subjects the insulation to mechanical strain at the corners and weakens it.

Fig. 394.

Fig. 395.

Fig. 396.

Fig. 397.

Methods of Slot Insulating.

One advantage of form-wound coils is that they may be wound, packed, and transported separately, and not assembled on the armature until the machine is erected on site, which is more safe than transporting a large wound armature.

Also, on the question of repairs on site, it is generally easier to replace a form-wound coil. To wind a coil on site by hand is, however, not a long nor difficult process. The hand-wound machine with closed or semi-closed slots gives a more even wave shape than the open slots, but the inductance of the winding is rather greater.

B. *Lap-coil Windings.*—When the conductor is wire or small strip, the coils will be very similar to certain coils of continuous-current armatures. Examples of these types of windings may be seen in Chap. XI. The style of coil and winding form will be very similar to those described in that chapter.

When there is only one conductor per slot (or at most two) the winding will be carried out as a bar winding, and the process will be precisely the same as for bar-wound wave windings except that the coils are lap instead of wave connected.

We shall deal with bar windings under the heading of wave windings, as such are most frequently wave windings.

C. *Wave Windings.* Bar Windings.—The first bar winding we consider may consist of straight bars with V-end connectors at each end.

Fig. 398.—Portion of Armature Core and Bar Winding of Westinghouse Alternator.

Fig. 398 shows a portion of a finished armature wound on this plan.

The first operation will be to cut up the bars to the correct length. In this case the gross core length of the armature is 63 cms., and allowing 20 cms. overhang at one end and 10 cms. at the other, the total length of the bar must be 93 cms. After cutting up to this length the ends are filed up smooth or ground on a rough emery wheel, and then the bars are taped up, leaving the ends bare for the joints.

The bars are then inserted in the slots by pushing them in from the end of the armature, each successive group of four projecting further from the slots alternately, as seen in Fig. 398.

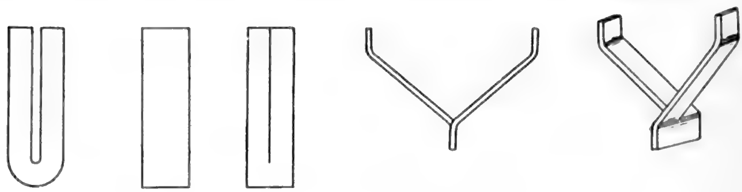


Fig. 399. Fig. 400. Fig. 401.

Formation of V-end Connectors.

The end connectors are made from copper strip, which is first bent round to the shape of Fig. 399 in any of the strip-bending presses described in Chap. XI., p. 274.

An alternative is to take a broad sheet of copper and split it nearly to the end, as in Fig. 400.

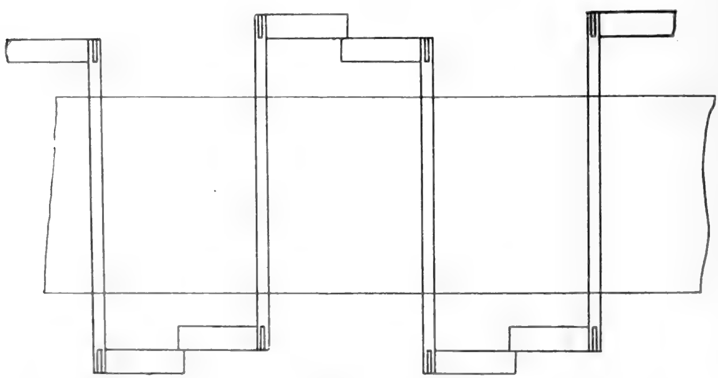


Fig. 402.—Element of Bar Winding.

The result of either Fig. 399 or 400 is then spread out to the V shape, and the ends bent up straight as in Fig. 401. The V connectors thus formed are taped up except at the ends. (In very low voltage machines the taping might be dispensed with and the connectors simply varnished.)

The bars are now connected up successively according to the winding diagram. An element of this wave winding so connected is shown diagrammatically in Fig. 402.

The joints between the bars and connectors may now be made. This may be done in a number of efficient ways:—

If the connectors are of thin strip which is fairly flexible, their ends may be wrapped once round the bar and the joint sweated up. If the bars and connectors are very heavy, the joints are sometimes secured with screws or rivets and afterwards soldered. Fig. 403 gives a number of alternate methods of making a suitable joint.

The above method requires two joints for every conductor, but the number of joints may be halved by shaping the bar as in Fig. 404, which can still be used with closed or half-closed slots.

If the slots are wide open, the number of joints may be halved by shaping the bars as in Fig. 405. Another alternative (which has, however, two joints per bar) will be seen in Fig. 270, Chap. IX. Fig. 406 is a photograph showing in detail the

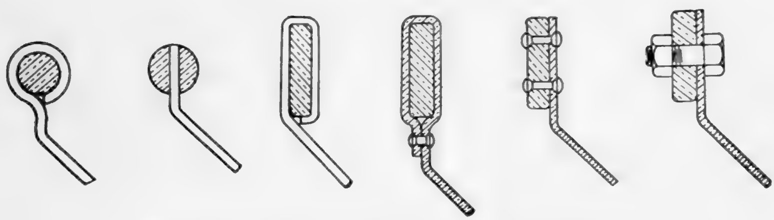


FIG. 403.—Methods of jointing Bars and Connectors.

terminals of a bar wound alternator of which the winding has already been referred to in Fig. 243.

D. *Retrogressive Wave Windings.*—An inspection of any of the winding diagrams in this class (see Figs. 273 to 278) will show that so far as the shape and connection of the coils are concerned, they are identical with ordinary wave windings for continuous-current armatures. The top conductors in one slot are connected to the bottom conductors in the next slot displaced from it by the winding pitch, as in a continuous-current armature. With this identity in mind we need only refer back to the winding of continuous-current wave-wound armatures to meet the requirements of the present case. One point that should be noted is that with this type of winding the top and bottom sets of conductors in the slots must be insulated from each other, as high pressures exist between them. For this reason the winding is not favourable to very high voltages. This winding is equally adaptable to wire or strip windings.

E. *Skew-coil Windings.*—This type is not common, and does not require much attention. The shape of the coils will be seen from Fig. 234. Such a coil may be wound by hand over a block similar

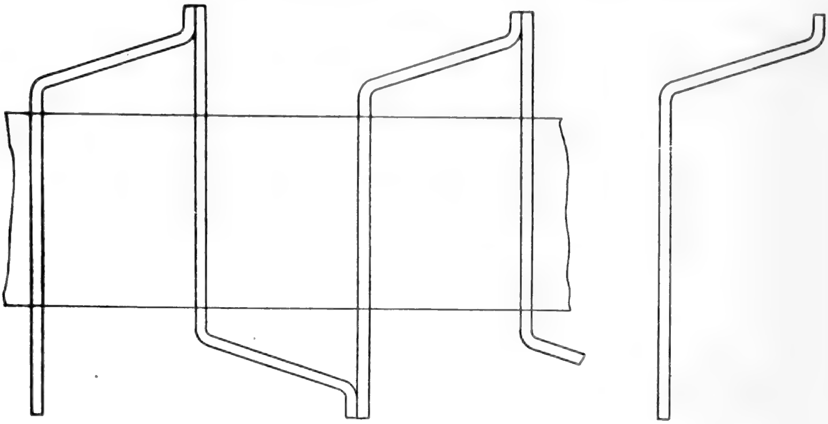


Fig. 404.—Bar Winding with one Joint per Bar.

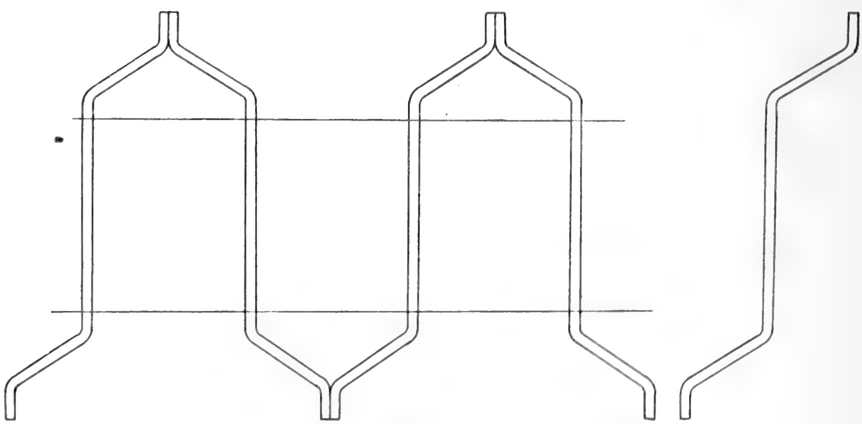


Fig. 405.—Bar Winding with one Joint per Bar.

to any of those already described under hand coil windings (p. 301), except that the top of the block must be suitably shaped to give the coil its skew shape, which is not a difficult matter.

As we noted on p. 195, there will be some difficulty in winding the last coil, as one part of it is behind the next adjacent one.

This difficulty is obviated if the coils are form-wound and slipped in through the mouth of wide-open slots.

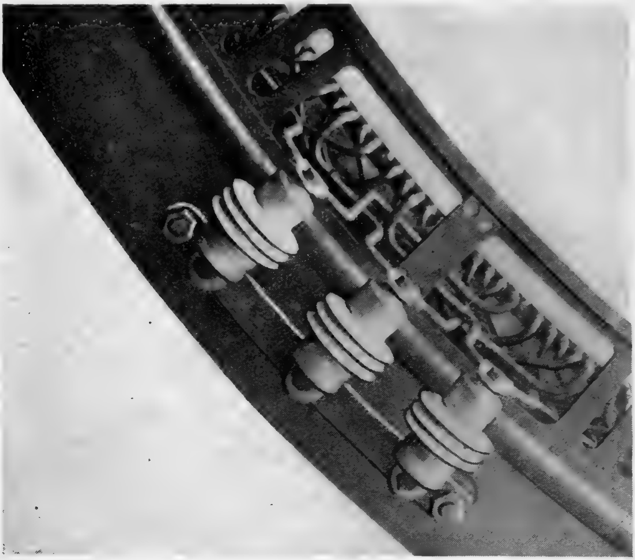


FIG. 406.—Terminals of Bar-wound Alternator (Lahmeyer Co.).

F. *Short-coil Windings.*—The coils in this case are all similar, and they may be hand or form wound, according to the type of slot, by any of the above described methods. This will also be the case with single-phase coil windings.

CHAPTER XIII

FINISHING AND TESTING

Banding.—Rotating armatures having open slots are generally banded round with a number of turns of steel wire at several points along the armature core to secure the coils in the slots against centrifugal force. The alternative to this is to close the mouth of the slots with a thin wedge of fibre or hard wood, engaging in recesses in the sides of the slots.

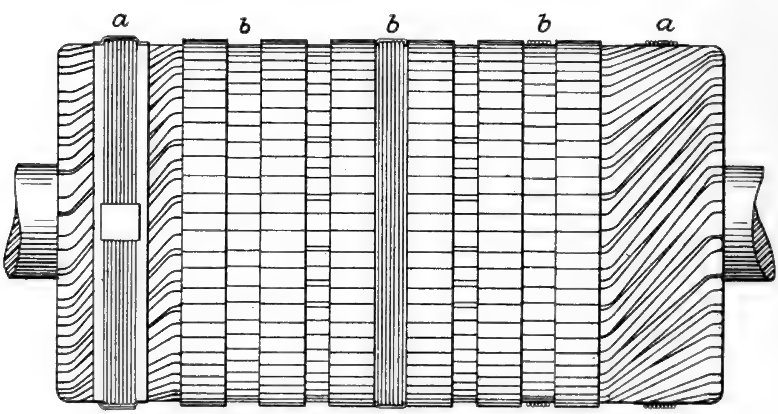


FIG. 407.—Armature with Binding Bands.

Up to a few years ago, the binding bands were commonly put on outside the surface of the armature core and standing up above it. If the clearance between the armature and field is small, this becomes dangerous with increasing wear of the bearings. The bands are now customarily recessed into the core so that they appear flush with, or slightly below, the surface, as in Fig. 407. Finished armatures banded up will be seen in Figs. 349 and 360 of Chap. XI.

In addition to the bands on the armature core the end windings are banded. This is necessary whether the bands on the core are replaced by wedges in the slots or not. Fig. 408 illustrates the method of applying the end bands.

The tension may be put on the wire by clamping it between two blocks, but the method shown in Fig. 408 is more satisfactory, although a crude arrangement.

Another way is to take one, two, or three turns of the banding wire round a piece of brass or gun-metal barrel, fixed firmly at the

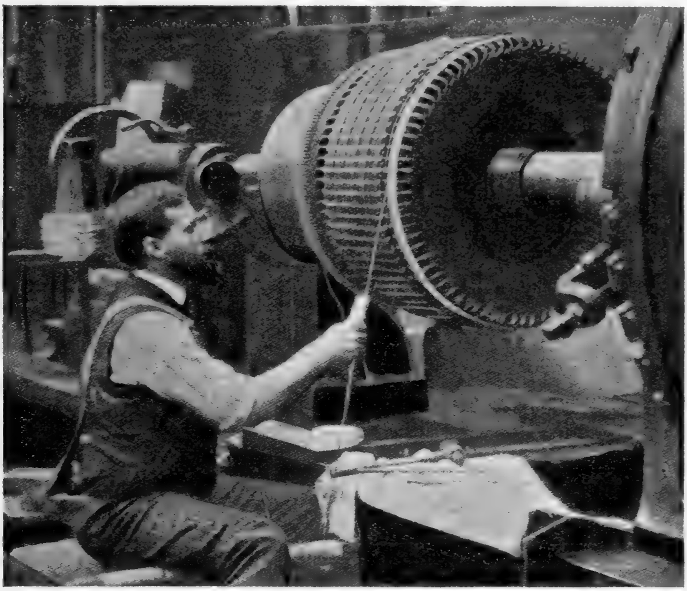


FIG. 408.—Banding Armature (Westinghouse Co.).

bed of the banding lathe. The tension should be adjusted with considerable care, and the wire should not be of too small gauge. The bands must be tight enough to prevent them from being displaced sideways. The bands are wound over a layer or two of insulation, which should be of sufficient thickness to prevent the coils sustaining any damage.

As an example, the Westinghouse No. 12A Railway motor armature has seven bands on it—four on the core, $\frac{5}{8}$ inch wide, and one on each of the end windings and one on the commutator leads. The bands on the core are insulated by one layer of mica and fullerboard, and the end windings are protected by one layer of bond paper with two layers of elastic tape. The insulation is of such width as to leave $\frac{1}{8}$ inch on each side of the bands.

The banding wire is 0·045 inch diameter medium hard steel, tinned. The tensile strength of this wire is about 204 lbs., and the tension put on the wire during banding is about 100 lbs.

After the recess in the core is filled with the banding wire, it is soldered up.

The wires are held by small clips of tinned copper, which are applied in the manner of Figs. 409 and 410, being placed under the wire during banding, and closed over as in Fig. 410 when all the wire is on. There would be four to six clips for each band on armatures up to half a meter diameter, and on larger armatures one clip for about every 25 cms. of periphery. The

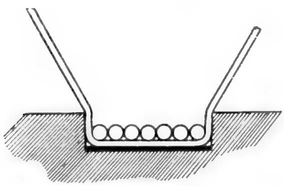


Fig. 409.

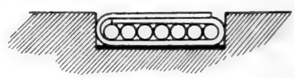


Fig. 410.

Clips for Binding Bands.

clips are then sweated up, and solder run in all round the wires on each band.

The soldering should be very carefully done, and care should be taken that the wire is clean from any grease or oil before soldering.

In larger factories it is customary to provide special lathes exclusively for banding. Fig. 411 shows one such machine. This runs at about 30 r.p.m. It has a self-contained tension and feeding attachment, the latter of which is seen in front of the lathe bed.

Fig. 412 illustrates another machine for this purpose. It will take armatures up to 31½ inches diameter and 98 inches length of shaft. The machine is electrically driven with a 1½-h.p. motion in the base of the headstock.

The headstock spindle has four speeds, 12, 24, 100, and 200 r.p.m., operated by a single lever.

The wire feed carriage is traversed bodily by rack and pinion from the one binding place to the other, while the top wire guide, on a screwed spindle of a pitch corresponding to the thickness of the banding wire, is fed forward by a hand wheel when banding. At the back of the lathe the carriage has extension arms with a drum for carrying the coils of wire.

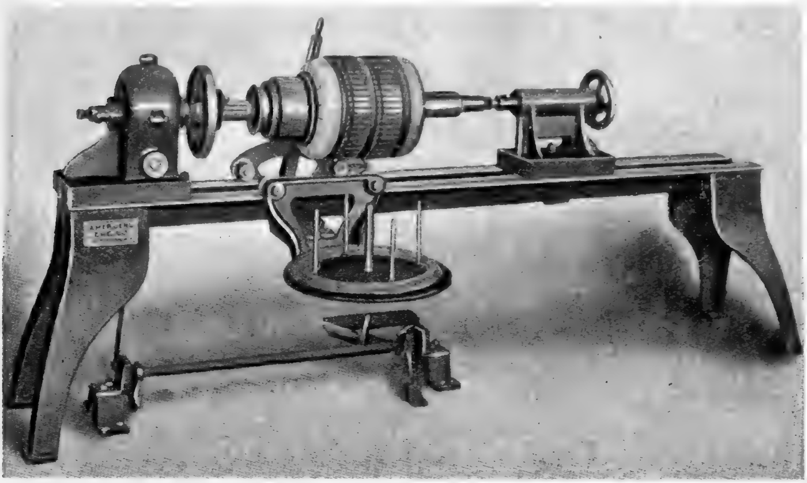


FIG. 411.—Armature Banding Lathe (American General Engineering Co.).

The motor drives through an intermediate shaft, which is instantly thrown in and out by means of a coupling actuated by a treadle running under and along the whole length of the bed.

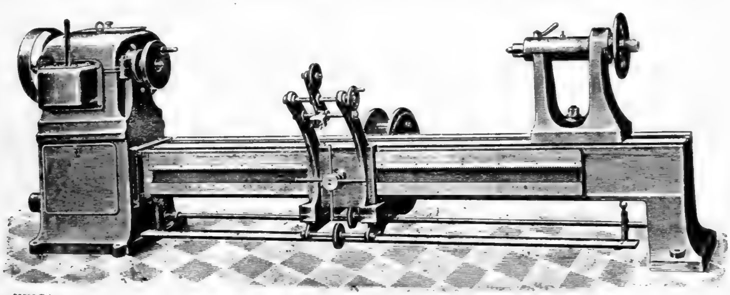


FIG. 412.—Armature Banding Lathe (Neville Bros.).

Balancing.—With ordinary types of armature, balancing for static balance is sufficient; but with high-speed armatures for turbine machines the dynamic balance is very important, and in the latter case the armature has to be run and balanced for absolutely steady running. The simplest method of adjusting for static balance is to mount the armature on a pair of knife edges, as roughly indicated in Fig. 413. The knife edges must be set up absolutely level with the aid of a spirit-level, and should also be parallel. When the armature is placed on them it will roll until the heaviest part is at the bottom, and balance weights are applied at a point diametrically opposite this.

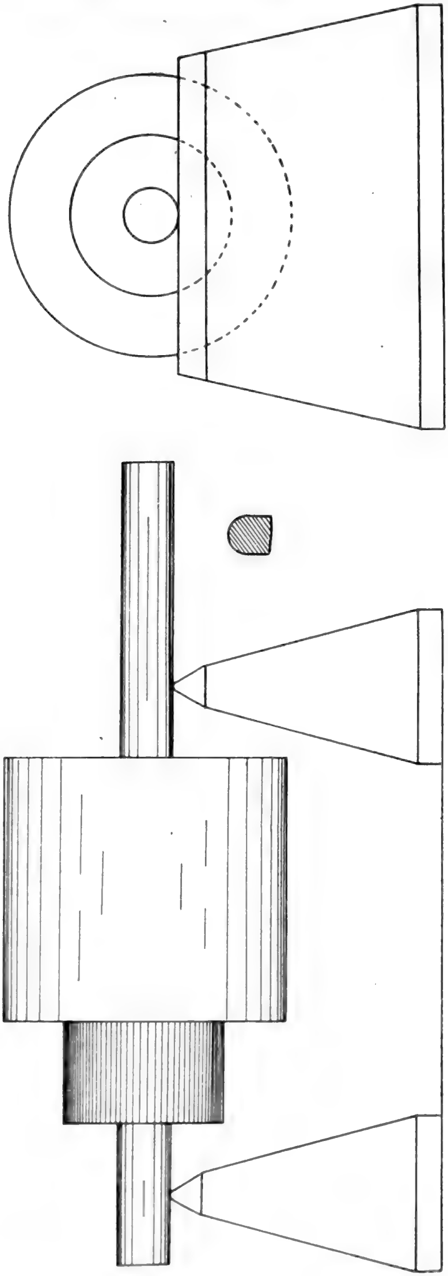


Fig. 413.—Simple Balancing Arrangement.

A better form of balancing table is given in Fig. 414. In this type, accurately ground and polished rings are put on the armature shaft, making a very sensitive bearing, and guarding the shaft against any damage that might be caused if the knife edges are rather sharp.

When the armature has taken up a steady position (with the heaviest part lowest), the balance weights are applied at the lightest part. These balance pieces may consist of small pieces of lead or white metal screwed on with one or two screws; or if suitable recesses are left on the spider to receive balance weights, the metal may be cast in.

In accordance with another method, instead of adding weight, some of the metal is taken away at the heaviest part. If the spider and end flanges permit of this, a good way is to drill out countersinks with the point of a twist drill until the right amount of weight has been taken off. This is, of course, not permissible if the balance is bad and requires a lot of adjusting.

Testing.—When finished, the armature is tested with a pressure of at least twice the normal working voltage. For street car and railway motors the test pressure is more usually of the order of five times the working voltage.[1]

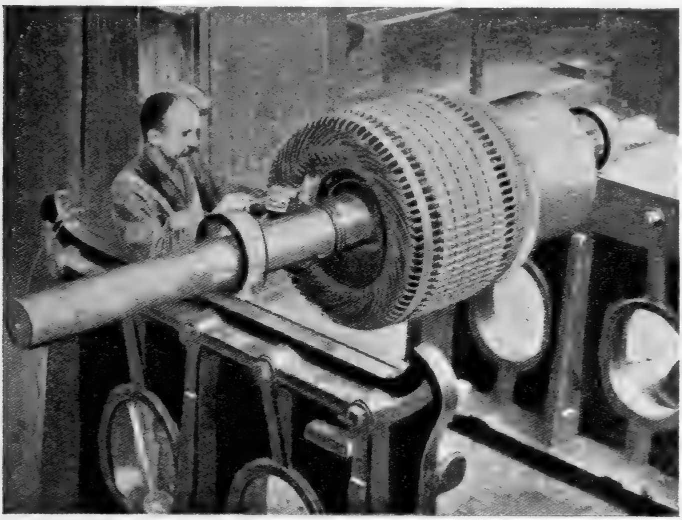


FIG. 414.—Balancing Table for large Armatures (Westinghouse Co.).

For high-pressure alternators up to 10,000 volts the test pressure is at least double the normal voltage. These testing voltages should be applied across the insulation between the windings and frame, and between electrically independent windings.

After the high pressure test the armature insulation may be measured with an ohmmeter or testing set for purposes of record.

Testing of Armatures during Winding.—The above-noted insulation tests are usually applied to continuous-current armatures immediately before connecting up the winding to the commutator

[1] See *Insulation of Electric Machines*, Chap. xxii., "Specification for Insulation."

as well as to the finished armature. During winding, tests should continually be made for short circuits in the winding or faults to the frame.

The most convenient idea for this is the "lamp-test," which consists simply of detecting continuity of any circuit by putting it in series with a lamp, as outlined in Fig. 415. The lamp is fixed where it is visible from the winding bench and a pair of loose wires *a* and *b* are accessible to the job.

To test if there is continuity through a coil (which is im-

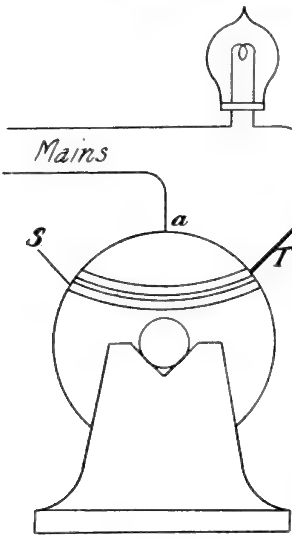


Fig. 415.—Lamp Test for Short Circuits.

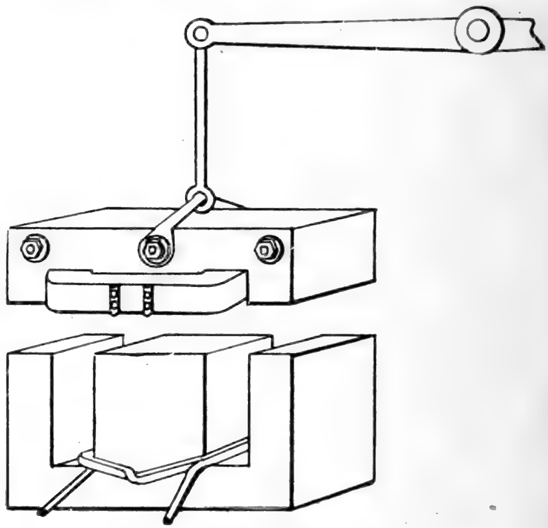


Fig. 416.—Transformer for Testing Form-wound Coils.

portant in the case of small wires which may get broken during winding) the ends *a* and *b* are put on the terminals S and T of the coil, and the lamp will light if the current is not broken.

To test if the winding has gone to frame by damaged insulation, one wire from the lamp circuit (*a*) is connected to one terminal of the winding and the other (*b*) put on the iron of the armature. If there is a fault the lamp will light, and if this is done on each coil individually after it is wound, a fault is at once located and the damaged coil can be at once rewound.

Instead of a lamp a bell circuit could be, and often is, used.

It is desirable with alternating windings to ohmmeter each coil after winding.

Form-wound coils should be tested individually, and a testing transformer suitable for this is shown in Fig. 416. The top half of the transformer contains the exciting coil supplied with alternating current, which induces E.M.F. in the form-wound coil under test when in the position shown.

Location of Faults in Armatures.—A faulty coil in a finished armature may be readily detected by placing the armature on a transformer such as that shown in Fig. 417, the principle of which is the same as the one in Fig. 416. For stator armatures a similar transformer is shown in Fig. 418. In this, one will note the difference in diameter of the upper and lower surfaces enabling

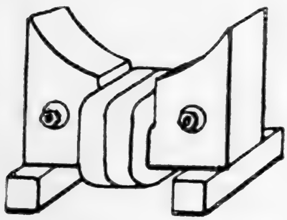


Fig. 417.—Testing Transformer for Wound Rotating Armatures.

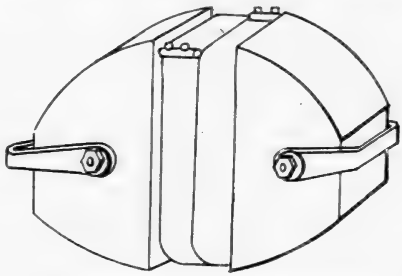


Fig. 418.—Testing Transformer for Wound Stators.

the transformer to be used for armatures of very different internal diameter.

A method suitable for polyphase motors is the following. If there is a fault in the stator winding, replace the rotor by an unwound rotor; then with the phases independent connect one phase to the alternating current supply and measure the voltage across each coil of the other phase, when the faulty coil will show a low reading. This can be done on each phase in succession until the faulty coils are located. If the fault is in the rotor winding, if coil wound, a similar test can be made.

INDEX

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